Adaptation and Invention during the Spread of Agriculture to Southwest China

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Abstract

The spread of an agricultural lifestyle played a crucial role in the development of social complexity and in defining trajectories of human history. This dissertation presents the results of research into how agricultural strategies were modified during the spread of agriculture into Southwest China. By incorporating advances from the fields of plant biology and ecological niche modeling into archaeological research, this dissertation addresses how humans adapted their agricultural strategies or invented appropriate technologies to deal with the challenges presented by the myriad of ecological niches in southwest China. This dissertation uses ecological niche modeling to examine the options and constraints associated with practicing different types of agriculture in the specific ecological niches of southwest China. The predictions made by these models are then tested against archaeobotanical data from a series of sites from across the region. This approach allows one to understand how the spread of agriculture took place in its particular social and economic contexts.

Table of Contents

CHAPTER 1 INTRODUCTION
Overview of the dissertation

CHAPTER 2 HUMAN BEHAVIORAL ECOLOGY AND THE SPREAD OF AGRICULTURE
Approaches to understanding the spread of agriculture: Europe
Rethinking the spread of agriculture
Behavioral ecology
Applications of human behavioral ecology to archaeology
Critiques of human behavioral ecology models
Applying optimization models to the spread of agriculture
Summary

CHAPTER 3 METHODS
Ecological Niche Modeling
Analysis of risk
Acquiring data to test the model: methods of archaeobotanical analysis
Statistical analysis in archaeobotany
Summary

CHAPTER 4 THE BIOGEOGRAPHY OF SOUTHWEST CHINA
Geology and geography of Southwest China
Current vegetation patterns
Ancient climate
Summary

CHAPTER 5 DOMESTICATES IN SOUTHWEST CHINA
Rice
Broomcorn and foxtail millet
Wheat
Barley
Buckwheat
Crops and labor
Summary

CHAPTER 6 SPREAD OF MILLET AGRICULTURE AND EARLY ADAPTATIONS ON THE PERIPHERIES OF THE SICHUAN BASIN
Origins of millet agriculture in the North China microlithic
A hunter-gatherer legacy in southwest China?
Spread of millet agriculture to the Sichuan highlands
Spread of millet agriculture to the Tibetan plateau
Spread of millet agriculture to the Chengdu Plain

Spread of millet agriculture to Yunnan-Guizhou and Southeast Asia
Ecological niche modeling and agricultural strategies in the spread of millet farming
Crops, languages and population movement in Southwest China
Summary

CHAPTER 7 THE SPREAD OF RICE AGRICULTURE: THE CASE OF THE SICHUAN BASIN AND THE YUNNAN-GUIZHOU PLATEAU
The spread of rice agriculture to the Sichuan Basin
Changes in subsistence patterns on the Chengdu Plain
Microbotanical analysis at the site of Baodun
Agricultural strategies on the Chengdu Plain during the Baodun period
Spread of rice agriculture beyond the Sichuan basin: Yunnan, Guizhou and Southeast Asia
Ecological niche modeling and the spread of rice and foxtail millet agriculture to Southwest China
Human niche construction and the introduction of Champa rice
Summary

CHAPTER 8 AGRICULTURAL STRATEGIES ON THE CHENGDU PLAIN
The Bronze Age of the Chengdu Plain
Changes in crop composition during the Bronze Age on the Chengdu Plain
Weed flora assemblages and changing agriculture strategies on the Chengdu Plain
Crop processing and changes in labor organization on the Chengdu Plain
Summary

CHAPTER 9 CROP GLOBALIZATION AND INNOVATION: LATER HISTORICAL TRENDS IN THE SPREAD OF AGRICULTURE TO SOUTHWEST CHINA
Spread of West Asian domesticates to East Asia
Wheat and barley in Western Sichuan
Western domesticates on the Sichuan Basin
Movement of western domesticates onto the Tibetan plateau
Ecological niche modeling and the spread of western domesticates
Epilogue: The Columbian exchange and ecological adaptations in Southwest China
Summary

CHAPTER 10 CONCLUSION

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CHAPTER 1

INTRODUCTION

Understanding how, why and by what mechanisms agricultural practices, technologies and products spread from zones of original development is a central theme of archaeology. This dissertation presents the results of research into how agricultural strategies were modified during such a spread into southwestern China from other regions of East Asia, as well as, from West or Central Asia. In particular, I address how humans adapted their agricultural strategies or invented appropriate technologies to deal with the challenges presented by the new ecological niches characteristic of the environmental conditions of what are now the provinces of Yunnan, Guizhou, Sichuan and Chongqing. This region is ecologically diverse and contains a variety of ecosystems including the foothills of the Himalayas, the rugged landscape of the Yunnan-Guizhou plateau and the Three Gorges, and the low lying plains of the Sichuan Basin (Figure 1.1).

In prehistory, Southwest China became an important center for socio-political complexity that developed independently from that of the Central Plains (Flad and Chen 2013). The spread of agriculture to this area held important implications for the later development of social complexity in the region. In particular, this spread eventually led the Chengdu Plain of the Sichuan Basin to become a population center and breadbasket

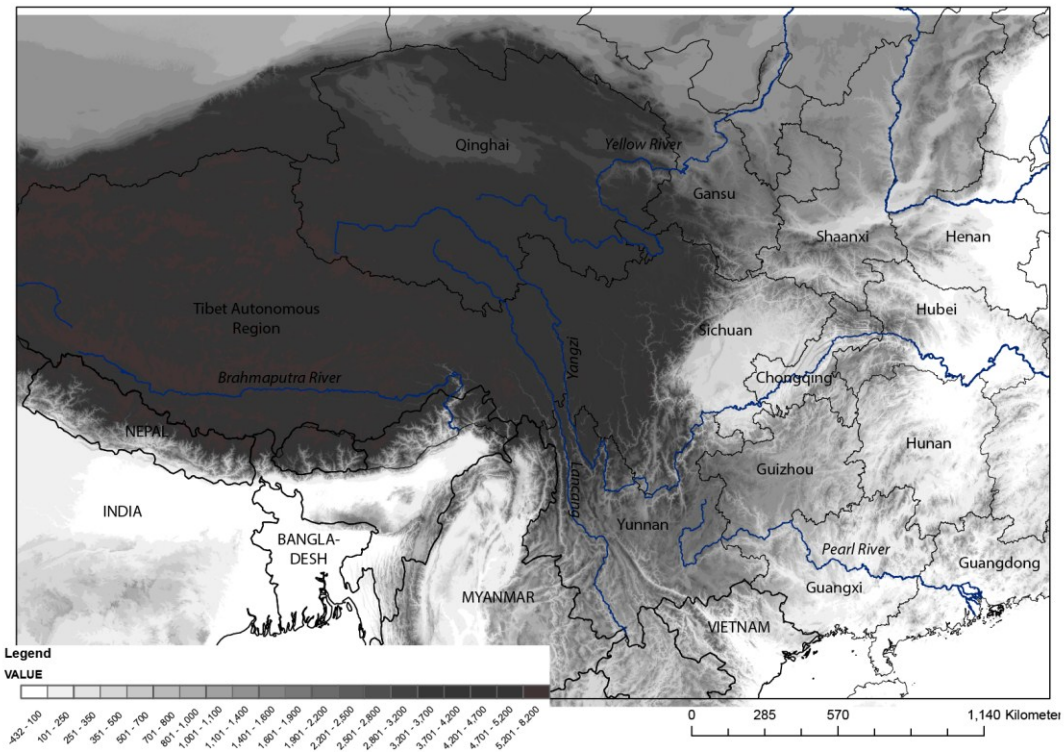

Figure 1.1 Map of the region of Southwest China. Southwest China, as defined here, is composed of the regions of Chongqing, Sichuan, Yunnan, Guizhou, and the Tibet Autonomous Region.

throughout dynastic Chinese history as well as the lynchpin for the first unification of China in 221 BC (Sage 1992). Despite the importance of agriculture for the development of social complexity, however, relatively little is known about its spread across China beyond its areas of first development in the Middle Yellow River, Middle Yangzi, and Lower Yangzi alluvial zones. And although agricultural intensification is described as a major causal factor in the development of complex societies, we still have little understanding of the mechanisms by which agricultural intensification occurred in Southwest China. The remains of ancient plants provide the most direct evidence for understanding how transformations in the agricultural regime took place. Up

to now, however, research has primarily used plant evidence to establish when and where agriculture first originated with little emphasis on how agriculture moved out of its original homelands in China and on how changes in subsistence regimes articulated with social change across ancient China.

In China to date, when studied at all, the spread of agriculture has been looked at primarily as a way of understanding the movement of prehistoric cultures and of traditions of cultural material sensu *quxi leixing* (Su and Yin 1981; Wang 1997; Yan 1987). While such studies have outlined possible directions for the spread of agriculture across this region (Zhang & Hung 2010), the processes by which such spread occurred have not been a primary focus of discussion. This has been complicated by the fact that, prior to the present work, very little systematic archaeobotany has been carried out in Southwest China, and the reliable dates needed for understanding when and how this spread occurred are lacking. As result, little emphasis has been placed on the manner in which agricultural packages became adapted to new environments. Even when archaeobotanical data have been brought to bear on understanding the spread of agriculture into this region, only one crop has been emphasized, namely, rice. The important roles played by other crops, such as millets, have been largely neglected.

Following the domestication of rice beginning c. 7000-6000 cal. BC[1] in the Middle and Lower Yangzi river valley (Crawford and Shen 1998; Fuller, Harvey and Qin. 2007; Fuller, Qin and Harvey 2008;a,b; Liu et al. 2007; Zhao 2010f), agriculture appears to have taken more than 3000 years to spread to the southwest. The reasons for this delay remain far from clear. My research has sought to understand those reasons, with the result that this dissertation presents and

[1] All dates are calibrated radiocarbon determinations.

discusses hypotheses as to why Southwest China formed a barrier to the movement of agriculture for such a long period of time.

More broadly, this dissertations aims to outline a series of methods for understanding how humans made behavioral choices relating to their subsistence regimes and how they adapted older methods or developed new ones so as to be effective farmers in new and challenging environments. Using models based in behavioral ecology and ecological niche modeling, I describe a series of analytical approaches to understanding the constraints that ancient agriculturalists faced in the past. I test the predictions of these models against archaeobotanical data derived from the region of Southwest China.

My approach does not adopt uncritically the diet breadth and patch choice models developed specifically for foragers. Instead, I use behavioral ecology's general approach by attempting to make explicit the variables that went into choices to adopt or reject a new crop or to intensify agriculture. In order to do so, I use ecological niche modeling to examine the options and constraints associated with practicing a given type of agriculture in the ecological niches of Southwest China that were different from those in which five different crop plants were originally domesticated – rice, foxtail millet, broomcorn millet, wheat and barley. To date, researchers in archaeobotany have only looked at one aspect of crop phenology – length of growing season – to understand the challenges that agriculturalists faced in moving crops into new environments (Boivin, et al. 2012; M. Jones, et al. 2011). That measure, however, is rarely used by plant biologists and ecologists because other measures, such as the cumulative heat requirements of a plant (growing degree days), provide better estimates of where crops can be grown. By introducing recent advances in our understanding of crop growth to archaeological research, and by acquiring accurate data on the growth of these plants through experimental

studies, I have developed a methodology to better predict the constraints that would have been faced by ancient agriculturalists as they moved their crops into new ecological niches and as then existing niches came to be transformed due to climate change.

In order to understand how these processes took place in the context of Southwest China, I examine archaeobotanical remains derived from two different datasets: samples collected and analyzed by me from archaeological contexts on the Chengdu Plain of Sichuan Province and previously published datasets from the highlands surrounding that area.

Overview of the dissertation

Chapter 2, *Human Behavioral Ecology and the Spread of Agriculture*, outlines, how, in other areas of the world, researchers have dealt with the spread of agriculture. In doing so, I put most of my focus on the case study of Europe because it is the best documented. I then discuss the usefulness of a theoretical framework based in human behavioral ecology (HBE) for understanding the spread of agriculture outside of the original homelands of the concerned plants. Reviewing how approaches based in HBE have been applied to the study of ancient agriculture, I argue that models employed to date are not suitable for use in the study of agricultural societies. In contrast an approach informed by both HBE and Ecological Niche Modeling (ENM) is able to reveal important patterns underlying the spread of agriculture by clarifying the roles played by environmental conditions and by the physiological and developmental characteristics of the domesticates concerned in influencing how such spread took place.

Chapter 3, *Methods*, outlines how recent innovations in the field of Ecological Niche Modeling can be brought to bear on understanding the spread of agriculture. In this chapter, I describe how I have used growing degree days to map the potential niches of crops in Southwest China. Using daily temperature data derived from a number of weather stations in China, I map the thermal niches of these crops using co-kriging in GIS. This chapter also describes how the risk associated with practicing each of these crops was assessed. Finally, this chapter summarizes the methods that were employed to collect the archaeobotanical data used for this dissertation and the statistical methods used to analyze them.

Chapter 4, introduces the biogeographical context of Southwest China, describes the region's main geographic features, and reviews its current vegetation. The evidence for ancient climate change is also summarized. This review describes how, unlike areas of similar latitude in eastern China, southwestern China contains a wide array of different ecological niches. The higher altitudes of this region are characterized by cooler temperatures than are similar latitudes in other areas. These factors created challenges to the movement of agriculture into the region.

Chapter 5, summarizes the history of domestication, the genetics and the physiological properties of five domesticates that came to play an important role in the agricultural history of Southwest China: rice, foxtail millet, broomcorn millet, wheat and barley. In addition, this chapter briefly summarizes the phenological properties of buckwheat. The level of labor intensity involved in growing these crops is also considered.

Chapter 6 reviews the evidence for the earliest spread of agriculture to highland Southwest China in the form of millet agriculture, accompanied by the spread of painted pottery and cultural material sharing affiliations with that of the Majiayao culture of northern China. Because of their short growing seasons and tolerance to aridity, millets served as pioneer crops that facilitated the movement of agriculture into these more challenging environments, while allowing early farmers to retain a high degree of mobility. Broomcorn millet and foxtail millet differ somewhat in their phenological characteristics, and appear to have been used as appropriate to specific environmental conditions in order to maximize returns and safeguard against risk. The resulting agricultural systems appear to have spread far beyond western Sichuan and were part of the first movement of agricultural production onto the Tibetan Plateau. I argue that, although the evidence for millet agriculture is limited due a lack of archaeobotanical investigations in the region as a whole, the millets were likely the first agricultural package to move into highland Yunnan and Guizhou and ultimately into mainland Southeast Asia.

Chapter 7 reviews the evidence for the spread of rice and millet agriculture to Southwest China. The earliest finds of rice agriculture in this region come from the Baodun culture, which occupied the Chengdu Plain beginning c. 2700 cal. BC. An examination of measurement data from rice grains in this region hints that the delay of the spread of rice agriculture into this region may have been due to the fact that it was necessary to wait for the development of varieties of rice better adapted to cooler conditions (i.e., temperate varieties of *Oryza japonica*). Ecological niche modeling carried out in this chapter reveals that the Sichuan Basin contains sufficiently high numbers of cumulative growing degree days to allow temperate varieties of rice to be grown. In particular, the large flat expanse of the Chengdu Plain, with its ample water sources,

provided an ideal environment for wetland rice production, one that shared some key characteristics with the middle and lower Yangzi. Conversely, this analysis shows that the areas surrounding the Sichuan basin, namely, the Three Gorges and Yunnan-Guizhou plateau, presented considerable challenges to the movement of rice agriculture. Archaeobotanical evidence from the site of Haimenkou has shown that, although rice agriculture was experimented with in highland Yunnan, this experiment quickly failed, and the inhabitants resorted to less riskier crops such as millet or they returned to foraging. During historical times, cultural values that dictated the importance of rice led to technological innovations in ecosystem engineering and in crop breeding that eventually transformed the Yunnan-Guizhou plateau into an area where rice agriculture was highly productive.

Chapter 8 takes a more detailed look at the samples derived from Neolithic excavations on the Chengdu Plain and extends this analysis to the Bronze Age of Sichuan Province. The highly complex societies of Sanxingdui and Shi'erqiao were sustained by a system of intensive and reliable rice agriculture, supplemented by much smaller contributions from dryland crops. Although this system was resilient in the face of climate change, a cooling event c. 2000 BC appears to have prompted the inhabitants of the Chengdu Plain to increase the numbers and diversity of dryland crops. Following this period, however, they returned to intensive rice agriculture.

Chapter 9 documents the arrival of western domesticates (wheat and barley) in Southwest China and examines the highly variable patterns of their adoption. This chapter reviews the evidence for the spread of these domesticates into highland and lowland Southwest China using data from

sites in the Chengdu Plain, Western Sichuan, and Yunnan Province. Finally, I discuss the current evidence for the introduction of these crops to the Tibetan Plateau. Using Ecological Niche Modeling, this chapter demonstrates that, contrary to previous arguments, wheat and barley were better adapted to the ecological conditions of highland Southwest China and Central Asia than were the millets, and, as a result, these crops ended up playing a crucial role in the economy of those regions. Unlike previous scholars, I argue that the delay in the spread of wheat and barley to East Asia was not because of their growing seasons being too long, but rather because the movement of these crops into more northern latitudes of Central Asia required the development of spring-sown phenotypes. That said, I also argue that cultural factors meant that wheat and barley were not readily adopted as part of the diet in areas where warmer temperatures permitted the successful development of rice agriculture.

I conclude that methods derived from ecological niche modeling and from an approach based on some tenets of human behavioral ecology can provide valuable tools for understanding human decision making relating to agricultural strategies in prehistory, particularly in the context of the spread of agriculture. By being able to accurately outline the series of constraints faced by ancient agriculturalists, this approach allows one to understand how the spread of agriculture took place within its particular social and economic context(s). Such an approach offers the possibility of providing valuable insights into ancient agricultural and land-use strategies and into how agricultural lifestyles became predominant around the world.

CHAPTER 2

HUMAN BEHAVIOURAL ECOLOGY AND THE SPREAD OF AGRICULTURE

In China, the focus of research to date has been on the origins of agriculture and on not its spread. This chapter begins by reviewing how, in other areas of the world; researchers have dealt with the spread of agriculture, using the case study of Europe as an example. I then discuss the usefulness of a theoretical framework based in human behavioral ecology for understanding how humans moved agriculture outside of its original homelands. Using this framework as a starting point, I then go onto discuss how an approach informed by behavioral ecology and ecological niche modeling can reveal important patterns underlying the spread of agriculture.

I describe how using such an approach can clarify the role played by the environmental conditions and the physiological and developmental characteristics of domesticates in influencing how this spread took place. Doing so, in turn, helps us understand why humans made the choices they did, whether due to environmental pressure, technology or cultural preference. By documenting what crops moved into Southwest China and when, I can then create hypotheses as to why people moved crops the way they did.

Research has already identified that agriculture arose around the world in roughly seven primary homelands. Through the application of systematic archaeobotany and zooarchaeology, the mechanisms by which hunter-gatherers moved from foraging to farming lifestyles are understood in increasing detail.

For many regions of the world, less is understood about how agriculture spread out of these original homelands. China is no exception. While recent studies have made much progress toward understanding the mechanisms through which foragers took on an agricultural lifestyle in roughly two Chinese centers of origin, relatively little attention has been paid to how agriculture spread from these centers to become the dominant lifestyle in East Asia between 6000-1000 BC. In particular, how agriculture spread to the orographically defined region of Southwest China is not well understood. However, it is clear that agriculture took well over 3000 years to move from its center(s) of domestication into this new environment. In order to outline methods of inquiry that are useful to understanding how agriculture moved into Southwest China, this chapter begins with a review of how the spread of agriculture has been understood by researchers working in other areas of the world. I use the example of Europe, an important secondary zone of agricultural adoption, where decades of systematic archaeological investigations mean that sufficient data have accumulated for us to be able to outline the processes underlying the spread of domesticates in that region of the world.

2.1) Approaches to understanding the spread of agriculture: Europe

The spread of agriculture through Europe has become one of the best understood of agricultural expansions. Large numbers of both salvage and planned archaeological research have taken place across the continent, and the wealth of data derived from these excavations has contributed to increasing our understanding of this issue. Between 6500 and 4000 BC, domesticates from the Near East spread across the European sub-continent, and Europe moved from being a zone of foragers to one dominated by peoples involved in an agricultural lifestyle. A number of crops

and animal species played an important role in this spread, including different varieties of wheat, barley, oats, and rye as well as a range of pulses and other crops (Zohary, et al. 2012). Along with these plant domesticates, animal domesticates such as pigs, cows, sheep and goats also moved into Europe. Data derived from a variety of different sources, including zooarchaeology, archaeobotany, human osteology, ancient DNA, radiocarbon dates, linguistic evidence, housing structures, and material culture such as pottery, stone tools and other implements, have been used together to document how this spread occurred. As a result, our understanding of the processes that led to the adoption of agriculture in this area have become increasingly clear.

Earlier research on the spread of agriculture focused largely on documenting the nature of the spread and on ecological explanations for how the spread occurred (e.g., Higgs and Jarman 1969, Hubbard 1976a,b). However, the advent of post-processual archaeology in the 1980s has led to a shift in focus in understanding how the Neolithic lifestyle emerged, emphasizing the development of a new structure of ideas. Much of the research in Europe has focused on identifying the individuals who were responsible for moving Near Eastern domesticates across Europe. Two main possibilities emerge: that these domesticates passed into Europe via trade and were adopted by local hunter-gatherer populations or that these domesticates accompanied migrating agriculturalists across Europe.

There are only a few instances where the presence of domesticates and cultural material alone can be used to argue for migration or colonization. One such scenario comes from areas that do not show evidence for prior occupation. An example of this comes from the site of Shillourokambos on the island of Cyprus (Guilaine and Briois 2001). At this site, clear evidence

for large-scale import of plants and animals (including wild cattle, boar and goats, deer, and even cats, along with emmer and barley) onto the island took place during the PPNB (10,500-9000 cal BP) (Vigne, et al. 2011; Willcox 2000). The complete lack of evidence for these species on the island prior to its colonization demonstrates that these plants and animals were brought onto the island by colonizers from other areas. However, contexts such as Cyprus are exceptional and, in many areas of the world, there is clear evidence for prior hunter-gatherer occupations. How can one then distinguish between migration of farmers and acculturation of hunter-gatherers?

Migrating agriculturalists are argued to have left important marks on genetic, linguistic and cultural aspects of societies around the world (Bellwood 2005c). In Europe, some argue that these migrations occurred as a "wave of advance" of agricultural populations from the Near East relatively swiftly moving across the continent (Ammerman and Cavalli-Sforza 1973, 1984; Cavalli-Sforza 2002). Proponents of this model have used a variety of evidence to support their claims.

Linguistic evidence for similarities in the vocabulary of Indo-European language groups has long hinted at massive population movement, although there has been much disagreement about the timing and the individuals involved. The idea that agriculture spread as part of demic diffusion by Indo-European speakers is an idea that has long been supported by Renfrew (1987; 1996), Bellwood and others (Bellwood 2005c; Bellwood and Renfrew 2002; Zvelebil and Zvelebil 1988). However, this point of view is not universally accepted. Anthony (2007) and Mallory (1989) have argued that, based on terminology for words like wheel and wagon, Indo-European

languages only spread into Europe after 3500 BC and do not appear to be associated with the spread of the earliest farmers.

In addition to arguments based on linguistics, typologies of cultural material have also been used to argue for population spread across the European continent. Evidence from sites belonging to the LBK (Linearbandkeramik) has been extensively used in support of rapid population movement from the East (Price 2000a). LBK sites show a high degree of homogeneity in pottery decoration and longhouse construction. The relatively rapid spread of LBK cultural material from Slovenia and Poland to the Paris basin over roughly 200 years has led many to argue that the LBK represents the movement of agricultural settlers across the European continent (Bellwood 2005c; Bogucki 2000, 2003; Scarre 2002). Others (Barker 1985; Price 2000b; Whittle 1996), however, have argued that the local variations of the LBK show continuity with previous Mesolithic cultural material, indicating that the processes accompanying its spread may have been more complicated than simple population movement and replacement.

Early proponents of Cavalli-Sforza's "wave of advance" theory argued that evidence from modern human blood groups indicated immigration from the Near East (Ammerman and Cavalli-Sforza 1984). Work on traits associated with skeletal morphology has also suggested a high degree of homogeneity among Neolithic populations in Europe (Pinhasi and Pluciennik 2004). These craniometric studies do not show any indication of similarity between Mesolithic populations and those that were agricultural, hinting that the spread of agriculture throughout Europe was associated with population replacement. How these traits are inherited, however, is far from clear, and the authors do not fully consider the role of population mixing. The increased

reproductive capacity and the demographic transition that took place in agricultural populations has been used to suggest that agriculturalists could have outnumbered Mesolithic hunter-gatherers, leading to an overrepresentation of their genetic material (Bocquet-Appel 2002; Boquet-Appel 2009).

Recent work on modern mitochondrial DNA shows patterns of genetic mixing that could have operated in a complex fashion. Some of this work has demonstrated that European maternal genetic material is more strongly associated with pre-Neolithic hunter-gatherers (Soares, et al. 2010; Soares, et al. 2009). Similarly, recent studies on modern Y chromosome markers indicate that only 50-60% of the population was derived from immigrants (Chikhi, et al. 2002). This could be the result of marriage patterns, whereby moving male agriculturalists took local hunter-gatherer women for wives. The date of this immigrant signature on the Y chromosome, however, is unclear. As Rowley-Conwy (2011) point out, these influxes could date to later periods of military expansion, such as the Roman Empire, or even later. The sequencing of the complete human genome as well as improved methods of extraction for ancient DNA will likely bring a greater understanding of the dynamics of population spread into Europe.

Explanations for the spread of agriculture in Europe, now tend to accept that at least a portion of the population that adopted agriculture were local hunter-gatherers. In the 1980s with the advent of post-processual archaeology, ideas about the spread of agriculture moved from being viewed simply as a change in subsistence, to there being a new structure of ideas (Rowley-Conwy 2004). As the subsistence economy came to be viewed as only a small part of changes taking place in a

larger way of thinking, scholars have tried to propose alternatives for how the spread took place (Hodder 1990).

To accommodate the complexity of the current genetic picture, scholars have proposed a number of modes of expansion as alternatives to the "Wave of Advance" model. These include "infiltration," whereby populations picked up local genes as they introduced agriculture and "leapfrog colonization" whereby agriculturalists moved into spaces unoccupied by hunter-gatherers (Bogucki 2000; Rowley-Conwy 2011; Zvelebil and Lillie 2000).

Aside from focusing on the identity of the movers of agricultural products, research has also examined the pace and the manner in which agriculture spread. By carrying out radiocarbon date interpolation, Pinhasi et al. (2005) have argued that the diffusion of agriculture into Europe took place rapidly, over a period of 100 generations, with agriculturalists moving across the continent at the speed of a kilometer per year (Pinhasi, et al. 2005). The authors point out that this corresponds to roughly two decades per move, which is approximately the time that children stay with their parents before moving out into the world (Pinhasi, et al. 2005; Robb and Miracle 2007; van Andel and Runnels 1995). Other studies have postulated, however, that the tempo of the spread of agriculture could have been highly variable depending upon geographic and cultural conditions. While it is true that agriculture may have taken only 1000 years to spread from Greece to Portugal, expanding into northern latitudes appears to have taken much longer. Similar delays appear to have occurred in the spread of agriculture to Southwest China, and as a result, it is important to consider the reasons underlying these delays in other parts of the world. It takes an extra thousand years for agriculture to spread into the British Isles, and even longer for it to

spread into Scandinavia. In particular, Isern and Fort (2010; Isern, et al. 2012) have argued that an agricultural lifestyle moved very slowly into northern Europe as a result of the higher density of local hunter-gatherer populations. It is also possible that the difficulty associated with growing Near Eastern crops in these northern latitudes could have delayed this movement (Bogucki 1996a, b), with some arguing that changes in climate to warmer conditions may have been necessary to permit agriculture to be moved into these areas (Bonsall, et al. 2002).

Archaeobotanical remains have formed an important part of the discussion about the spread of agriculture to Europe. As early as the 1970s, Hubbard (1976a, 1980) suggested that climatic constraints may have played an important role in constraining the northward movement of Near Eastern pulses and other domesticates into northern Europe. Colledge et al. (2004) have tried to address the question of how farming practices were adapted to European temperate environments. Their broad study, which grouped archaeobotanical data from over 166 sites, shows a strong geographic patterning of the aceramic Neolithic phases and a clear distinction apparently separating the Jordanian/Greek/Cypriot/Cretan sites and the Syrian/Turkish sites. Correspondence analysis revealed that different crops and associated weeds tended to characterize the different areas. However, College et al. (2004) attribute these differences to agricultural practice or cultural preference and not to biological or environmental conditions. For instance, they argue that free threshing species were not adopted because farmers moved so quickly into new territories that there was a bias against agricultural innovation, leading them to adopt a conservative strategy to guarantee success. It was thus only later in time, during the middle Neolithic Rossen culture (4600-4300 BC), that free threshing wheats were introduced. In later publications, this group also attributed major differences in crop composition to cultural

choice rather than to the biological properties of crops and their ability to adapt to different climatic zones (Colledge, et al. 2005).

More recently, others have argued that climatic conditions may have played a role in extending the time it took to be able to move plants into new areas and that a reduction in crop diversity occurred as plants moved into Europe (Conolly, et al. 2008). Some have argued that species of grass, such as domestic glume wheats and hulled barley, were not pre-adapted to the temperate climate in Europe (Bogucki 1996b). In contrast, Coward et al. (2008) argue that glumed cereals may have helped with storage and thus may have been preferred over free-threshing cereals. This could be a biologically based reason as to why certain species of the Triticaceae tribe (such as glume wheats, einkorn and emmer) were preferred over others (Coward, et al. 2008). Lentil and chickpea may have dropped out of the diet, as their longer growing seasons were maladapted to the conditions of a temperate climate. Conversely, the pea, which was better adapted to cooler climates, was retained (Coward et al. 2008). Other studies suggest that other properties of domesticates such as the development of a non-responsive photoperiod gene may have been essential to ensuring success in the northward movement of cereals such as wheat and barley (H. Jones, et al. 2011; Lister, et al. 2009).

The wide range of material available for studies of the spread of agriculture in Europe has meant that a research agenda focused on the identity of the movers of agricultural products has become possible. Research has focused on trying to find characteristics of pottery, linguistics or genetics that would allow us to tease Mesolithic and Neolithic populations apart. As Robb and Miracle (2007) point out, in cases where the Neolithic package is taken up as a “homogenous” package,

researchers tend to assume that migration has taken place, whereas in cases where it was taken up in a heterogeneous manner they argue for "acculturation." However, despite this preoccupation with understanding the identity of the movers of agriculture, some research effort has also been placed on trying to understand what kinds of factors motivated ancient foragers to adopt these new crops and on trying to understand the ecological constraints that farmers faced on the move.

The example of Europe has demonstrated the difficulty of determining who was responsible for the spread of agriculture, even with a considerable amount of data available. Compared to investigations in Europe, relatively little is know about the spread of agriculture throughout China as most investigations have focused on the areas that are considered to be primary centers for the emergence of agricultural systems (Barton, et al. 2009b; Bettinger, Barton and Morgan 2010; Bettinger, Barton, Morgan, et al. 2010; Bettinger, et al. 2007; Fuller, Harvey and Qin. 2007; Fuller, et al. 2009; Fuller and Weisskopf 2011; Jiang and Li 2006; Liu, Field, Fullagar, Bestel, et al. 2010; Liu, et al. 2007). Where such research has been carried out, it has focused primarily on identifying similarities in pottery and stone tool repertoires and relating those to the spread of migrant agriculturalists (Zhang 2008; Zhang and Hung 2010). As a result of this approach, migrationism has formed a major way of thinking about the spread of an agricultural lifestyle in East Asia. Indeed, some scholars have suggested that the southward dispersal of rice agriculture from the Yangzi river valley was related to the expansions of Austroasiatic- and Austronesian-speaking populations into mainland and island Southeast Asia respectively (Bellwood 2005c; Diamond and Bellwood 2003; Higham 2005; Hingham 2002).

Such has also been the case when thinking about South and Southwest China. For instance, Zhang and Hung (2010) argue that the expansion of agriculture into Fujian, Guangdong and ultimately Taiwan occurred as the result of rice agriculturalists spreading from the lower Yangzi. In particular, the absence of records relating to an earlier hunter-gatherer occupation of the region leads them as well as Liu and Chen (2012) to believe that the Xiantouling culture that occupied this region c.4000-3000 BC was the result of migrant agriculturalists from the Daxi-Tangjiagang culture in Hunan. While Zhang and Hung (2012) accept that some people may have retained a foraging lifestyle, because of an absence of evidence for rice cultivation, they nonetheless conclude that the earliest Neolithic in this region was an "exotic" introduction (Zhang and Hung 2010:19). In contrast, they argue that in Guangxi, the presence of a prior hunter-gatherer occupation in the form of the Dingsishan culture indicates that agriculture was adopted by indigenous hunter-gatherers, who were influenced by agricultural traditions on the Chengdu Plain and in the Middle Yangzi. When discussing the remains of the apparently foraging-based societies of the Gaomiao culture of the middle Yuanshui river and the Xia-Jiang and Yuxiping variants of the Chengbeixi-Daxi culture, close cultural affinities to surrounding farming societies lead them to argue that the inhabitants of these cultures were farmers who had turned to foraging due to environmental conditions (Zhang and Hung 2012). The paucity of archaeobotanical research in southwestern and southern China as a whole has made it difficult to establish whether or not these patterns hold true. As a result, the absence of prior evidence for hunter-gatherer occupation has led scholars to argue that the transmission of an agricultural lifestyle to this region occurred via migration, whereas the presence of a prior hunter-gatherer occupation with a continuation in pottery styles hints at acculturation or the spread of ideas.

The archaeological data that can be brought to bear on the issue of who was responsible for the movement of agriculture throughout East Asia are deficient in several regards. Firstly, in Europe, large numbers of systematic excavations and thousands of radiocarbon dates accumulated over the last 100 years mean that there is a high degree of chronological resolution. In China, in contrast, the situation is complicated by a shortage of radiocarbon dates in general and of contextually secure ones in particular. Secondly, genetic data for ancient migrations in China are also lacking. Thirdly, reliance on interpretations of traditions of cultural material alone, particularly with such low chronological resolution, cannot successfully be brought to bear on issues of identity. In sum, approaching the issue of the identity of the movers of ancient agriculture in China is a research question that is difficult to address given the current nature of the evidence.

That said, a better understanding of both animal domestication (Flad, et al. 2007; Jing and Flad 2002) and archaeobotany in China is beginning to emerge. The increasing availability of such evidence makes it possible to begin to understand how agriculture spread across China.

2.2) Rethinking the spread of agriculture

In Europe, a number of the studies reviewed above have moved from emphasizing "who" was involved in the spread of agriculture to answering questions about "how" the spread occurred and "why" it took the shape it did. Trying to approach the identity of the individuals who were involved in the spread of agriculture using the current archaeological evidence in China is likely to prove unsuccessful. Approaching the identity of the movers of agriculture is complicated,

even when well collected and well sampled culture historical, linguistic, osteological, and DNA data are available. In addition, identity is highly mutable (Diaz-Andreu, et al. 2005; Jones 1997), and there are a wide range of ways in which populations and individuals can change cultural identity. Furthermore, individual identities can change rapidly, while their DNA, physical morphology, and cultural material may not. An examination of the kinds of agriculture and crops exploited by groups does not provide enough evidence to make statements about cultural identity. Examples from North America have shown that some members of an identity group may take up a given food package, while other members may reject it (Robb and Miracle 2007). Given the lack of genetic and other data in China against which one could test hypotheses of who was responsible for the spread, I argue that an informative approach to the spread of agriculture lies not in identifying whether foragers or moving farmers were responsible for the spread, but rather in identifying behavioral changes in response to new environments and social situations (Smith and Winterhalder 1992a; Terrell, et al. 2003). Identifying these behavioral responses is important for understanding how humans met challenges in their subsistence practices in the past, regardless of the identity of the individuals involved. In anthropology, a variety of different theoretical and methodological frameworks have been used for identifying behavioral responses to challenges in subsistence practices. Two of these approaches are human behavioral ecology and niche construction. I argue below that while optimal foraging models derived from behavioral ecology form a useful heuristic framework for thinking about subsistence change, it is difficult to apply these models wholesale to the study of the ancient spread of agriculture. As a result, I borrow two general frameworks derived from this set of models: cost benefit analysis and niche modeling to inform how farmers met the challenges involved in moving their lifestyle around the world.

2.2.1) Behavioral Ecology

Optimization models developed in the field of behavioral ecology can provide a useful means of investigating change in human subsistence practices by identifying the underlying processes, decision making and selective pressures that are likely to have been involved in the these changes. Although these models have mostly been applied to foraging societies, they can also be useful for understanding agricultural change and how humans adapted agricultural systems to new environments. These models draw heavily on evolutionary ecology, which is defined by Smith and Winterhalder (1992a) as "the application of natural selection theory to the study of adaptation and biological design in an ecological setting" (Smith and Winterhalder 1992a:3).

Behavioral ecology arose from studies of animal behavior (ethnology), between the 1930s and 1950s. Behavioral ecology's premise was to use evolutionary theory to explain how animals adapted their behavior to their environments. It thus sought to find evolutionary and ecological reasons for particular behavioral traits. In early studies, Tinbergen (1951; 1963) outlined the four categories of explanation for behavior. These can be divided into *proximate* and *ultimate* (or evolutionary) explanations:

a.) *Proximate* explanations include two realms of inquiry. The first, *causation,* seeks to understand how processes in animals or humans work, without asking the question of why they came to be. The second, *ontogeny* or development, focus on how behavior is learned and considers the role played by the environment during the learning period in determining adult behavior.

b.) *Evolutionary* or *ultimate* explanations can be divided into those concerning *adaptation* (function) and *phylogeny* (evolution). In evolutionary theory, *adaptations* are traits that are functional to the reproductive success of organisms and that are the result of natural selection. *Phylogeny*'s primary goal is to elucidate when traits evolved and concerns all evolutionary explanations other than optimal adaptation.

While the proximate view seeks to explain how mechanisms work, the evolutionary view tries to explain why such changes came about (Tinbergen 1951; Tinbergen 1963). In order to explain why changes in behavior occurred, behavioral ecologists adopt a Darwinian perspective and assume that strategies and behaviors that ensure the ultimate reproductive success and survival of an organism will be selected for and will become dominant in a population. Traits, whether transmitted genetically or culturally, will follow the laws of natural selection. Different patterns of behavior or traits will have variable outcomes: some traits will help ensure an organism's survival, others will put an organism at a disadvantage, and still others will have no effect on survival. Behaviors that present a clear disadvantage to survival will have less likelihood of being passed on to future generations. Even though new traits or behaviors may appear rapidly, it often takes several generations for them to become dominant, and patterns may not always be observable over the short term. As a result, an approach based in a Darwinian paradigm is well adapted to investigations dealing with periods of time that span several generations. This approach assumes that even though they may be obscured by individual variability, patterns of behavior that tend towards optimality will become apparent over the long term.

Behavioral ecology specifically asks "why certain patterns of behavior have emerged and continue to persist and looks to their socioecological context in seeking answers" (Bird and O'Connell 2006:144). Behavioral ecology emerged as a field during the 1960s, when several seminal studies outlined many of the models and methods still applied to the field today (Charnov and Orians 1973; Charnov 1976 ; Hutchinson 1959; Hutchinson 1965; Lack 1954; MacArthur and Levins 1967; MacArthur and Pianka 1966; Orians 1969). The earliest applications of behavioral ecology to human populations date to 1970s (Denham 1971; Dyson-Hudson and Smith 1978; Wilmsen 1973). During the 1970s and 1980s studies of human behavioral ecology expanded rapidly, and the number of publications using a behavioral ecology framework increased dramatically (Winterhalder and Smith 2000).

Optimization Theory:

Human behavioral ecology looks to principles derived from optimization theory to account for human food procurement strategies. Optimization theory has proved useful for tying the theory of natural selection to empirical phenomena. Optimization models depend upon the underlying assumption that humans (along with other animals) will tend toward behavior that optimizes fitness and maximizes efficiency (Maynard Smith 1978). In biology, fitness is generally defined by reproductive success, which ultimately determines the contribution of an individual's genome to future generations. In order to increase the likelihood of their genes being passed on, successful individuals will adopt behavior that ensures and optimizes their own survival and reproductive capacity, including adequate nutritional intake and appeal to the opposite sex.

Optimization models are closely linked to the field of microeconomics, in which organisms are seen as rational actors, able to assess the cost and benefit or returns behind the exploitation of resources. In most economic applications of rational choice theory, rationality is defined as seeking the most cost effective means to achieve a specific goal. Underlying rational choice theory is the assumption that humans choose the best action according to stable preferences and constraints facing them.

Some schools of thought, have argued that rational choice theory does not provide a full description of reality and points out that models should only be used as a means of aiding reasoning (or interpretation) (Becker 1976). In particular, Sen (1977) has questioned rational actor theory's assumption that there is a pursuit of self interest in each act. As it is often impossible to empirically test the hypothesis that humans behave rationally, Sen, among others, has argued that rational choice theory is a tautology that becomes true by definition.

I do not argue that humans are essentially and invariably rational actors. I do argue, however, that humans will dynamically respond to constraints placed upon them by the biology of the species they exploit or by the environment in which they live. Rather, than using these models to understand what the optimal solution was for human subistence strategies in the past, and by extension trying to answer whether or not humans acted in an economically rational fashion, I argue that modeling can be useful in helping us outline the series of constraints facing early farmers and can help us come up with a series of possible solutions to these constraints. As a result, the type of modeling I employ does not try to identify patterns of rational economic choice but outlines what the parameters of possible choice are. I argue that identifying the

baseline of the possible is essential to understand before one can make statements about optimality.

One of behavioral ecology's strengths is its use of models to connect data and theory, to generate hypotheses, and to organize thinking (Winterhalder 2002). Models are intentionally simplified representations of reality that serve to highlight the effects of key variables, while reducing the noise from non-essential ones (Winterhalder 2002; Gremillion In Review). Models can be used in one of two ways: heuristically in order to organize thinking and collect data or to formulate and test hypotheses (Winterhalder 2002; Gremillion In Review). Human behavioral ecology models make use of microeconomic principles such as optimization, rational actor theory, efficiency maximization, and risk minimization in order to predict how humans might ideally have behaved, not necessarily how they did behave (Bird and O'Connell 2006; Smith and Winterhalder 1992b; Winterhalder and Goland 1997; Winterhalder and Kennett 2006a; Winterhalder and Smith 2000).

Human behavioral ecology (HBE) uses a number of different models to make predictions. These include diet breadth (prey choice), patch choice, the marginal value theorem, and variations on the central place foraging model. Some more recent applications of HBE to paleoethnobotany have moved beyond the concept of efficiency maximization to the concept of risk reduction. I briefly discuss the principles underlying these various models.

Constructing an optional foraging model:

Optimal foraging models are composed of four features: a *goal*, a *currency*, a *set of constraints*, and a *set of options*.

i.) *Goal*: Although in its traditional applications to hunter-gatherer societies, the goal is maximization of foraging efficiency, the goal can also be maximization of returns by the adoption of new crops, investment in water management regimes or labor, etc.

ii.) A *currency*: The currency can be a measure of energy, such as calories (kcal). Currency, however, can also be a more general measure of outcome such as "fitness", risk reduction, prestige or even free time (Gragson 1993; Hawkes 1990, 1991). Some critics have also argued that nutrients and the need for diversity in the diet and other factors (such as the non-food functions of a given resource, or its ability to be stored, or to be produced under adverse conditions) can outweigh the importance of calories (Smith 1983). The use of kcal as a currency is often largely inadequate, and in purely dietary concerns it has been argued that especially in environments where calories are abundant, a measure of the range of nutrients should be included as the currency and taken into account in modeling (Smith 1979). Humans require five types of basic nutrients to survive: carbohydrates, lipids, proteins, minerals and vitamins. While consumption of grains can technically provide enough calories for survival, it does not provide the proteins essential to the human diet, and it is necessary to derive protein from other sources such as meat or legumes. This is also true of minerals such as salt.

iii.) The set of *constraints* are limiting factors, such as a set amount of time one is able to dedicate to pursuing, harvesting or manipulating a resource or mitigating environmental restrictions.

iv.) The *set of options* are those choices available to the forager, including choices about how an individual will spend his/her time and choices regarding potential food resources (Kelly 1995, Smith 1983).

Creating detailed lists of the resources available to the forager or farmer is an essential component of these models as is documentation of the methods used to pursue and process them. These models assume that "a forager will decide which foods to take based on a knowledge of the quality of different foods and on a knowledge of resource densities (hence search costs or time spent locating the resource) and handling costs (hence return rates or the time it takes to harvest or pursue and process the process)" (Kelly 1995:83). The decision to pursue or not pursue a resource should entail a comparison of opportunity cost on the part of the forager (Winterhalder and Kennett (2006b). Using these models, the researcher can adjust variables (e.g., seasonality, resource depletion or exhaustion, procurement costs, new technologies that lower search and/or handling costs, environmental changes, etc.) in order to predict how a forager's diet ideally would adjust to such changes. The ranking of resources in a pyramid is an important part of such models as this allows one to predict how higher ranked and lower ranked resources could have be eliminated or incorporated into the diet (Hawkes, et al. 1982).

Two important models that are used to understand how individuals make these decisions are diet breadth (prey choice) models and patch choice models.

Diet breadth models:

Diet breadth models are used to predict whether a forager should take a resource (called "prey" in this case) if encountered. Diet breadth models assume an environment in which resources are distributed in a homogenous manner across the landscape. When a forager encounters a resource, he/she will either decide to take it based on a knowledge of its quality, resource density (search costs), and handling costs or will move elsewhere to find something better. When a forager decides to spend time acquiring or processing a different resource, he/she cannot simultaneously devote time to processing another resource. Thus in constructing a diet breadth model, *opportunity cost* must be taken into account. Diet breadth models divide the time spent acquiring the resource into two different periods:

1.) *search time* (or encounter rates) and;

2.) *handling time*

Search time accounts for the time it takes to locate the resource, and handling time account for the time it takes to process the resource once located. For each resource, the handling and search cost is described and ranked in terms of its *return rate* (Kelly 1995:78). The *return rate* is the amount of energy gathered per unit of time after encountering a resource. The researcher can adjust for variables such as improvements in technology that reduce search or handling costs, seasonality or resource depression.

Diet breadth models have been criticized because of their assumption that resources re evenly distributed across a landscape. In reality, resources are distributed in accordance with differences in microclimatic conditions, resulting in a "patchy" pattern.

Patch Choice Models:

The patch choice model addresses some of the concerns raised by critiques of the diet breadth model and are used to determine which resource patches (as opposed to which resources) should be included in a foray. This model assumes that resources are distributed across the landscape in a heterogenous fashion. However, like the diet breadth model it assumes that resources will be encountered at random and in proportion to their frequency. The "*Marginal Value theorem*" (Charnov 1976) was developed to determine at what point a forager should leave a patch for a new one. The *Marginal Value theorem* predicts that a forager should leave a patch when the returns from the patch diminish to the point that moving to another patch would provide a higher return rate, or when staying in a patch provides a lower return than the average for the overall environment (Stephens and Krebs 1986).

This model has, of course, numerous weaknesses, particularly the fact that foragers do not encounter patches at random. Foragers may choose where to forage based on a prior knowledge of the landscape.

Z-score or Risk models:

Risk or Z-score models were developed as a response to some of these critiques. Diet breadth models characterize how humans would behave if they maximize returns from resources. These models assume that the return rate from plants or animals is constant and not variable. All species, however, experience variation in their productivity due to local climatic or geographic conditions. Variability in the returns of a given resource can heavily impact return rate and hence the decision to continue to pursue a resource or not.

In behavioral ecology, risk is described as probabilistic variations in foraging returns (Stephens 1990; Stephens and Krebs 1986; Winterhalder 1990). Risk has been factored into the predictions made by human behavioral ecologists by using Z-score models (Caraco 1981, 1982). Z-score models recognize that two resources can have the same return rate but can have a lot of variance around the statistical mean.

Generally speaking the optimal reward is to choose the less risky option. Studies have shown, however, that when there is a likelihood that miminim caloric intake might fail to be met, individuals will tend to engage in riskier behavior (Caraco 1981, 1982).

Human foragers may also want to diversify or expand their diet beyond what a traditional DBM (Diet Breadth Model) might predict to reduce risk and safeguard against catastrophic losses. Winterhalder (1986) argues that sharing can be seen as a risk minimizing strategy as it pools the fruits of different individuals' foraging experiences. Storage can be another strategy used to deal with variability in yields (Gallant 1989; Winterhalder and Goland 1993). Diversification (as predicted by DBM models) can also be an important strategy for dealing with risk (Marston 2011). Diversification can occur in the form of adding additional resources to the diet in foraging contexts, planting new crops in an agricultural context, or exploiting different ecozones to ensure crop success and reduce variation in yield (Goland 1993; Marston 2011).

2.3) Critiques of HBE models:

Optimal foraging models are not without their critics. Critiques of the use of human behavioral ecology models centers primarily on two main problems: cultural choice and human niche construction.

2.3.1) Cultural choice:

By far the most common criticism of optimal foraging theory and its constituent models is that it cannot accurately account for the role of culture in determining which foods humans will choose to exploit (Betzig 1989; Cronk 1995; Joseph 2000; Laland and Brown 2011). In response to this criticism, human behavioral ecologists stress that the ways that reality differ from the predictions of the model allow researchers to identify where cultural characteristics come into play (Bettinger 1991; Kelly 1995; Smith 1983; Smith and Winterhalder 1992a). For instance, when an optimal foraging model predicts a particular species will be taken and in reality it is ignored (or the model predicts it should be excluded but in reality is taken), this should raise the question of 'why?'. For instance, if it is predicted that farmers should grow millet instead of rice, yet farmers still grow rice, we can then try to understand why by examining the cultural reasons people may have preferred one crop over the next.

Critics of HBE models may characterize behavior that does not fit these models as not rationally economic, but this critique fails to recognize that seemingly "irrational" behavior can still provide the actor with culturally-defined benefits such as prestige, attention or an insertion of ones behavior within a cultural norm. Indeed Max Weber proposed that rationality has two facets that he termed "instrumental" and "value" based (Weber 1948). The first is where humans seek to achieve their goals in an economically efficient fashion, while the second form of rationality is dictated by cultural values. He argues that individuals are constantly torn between these two options. Bettinger (1991) recommends that it is necessary to distinguish conceptually between each of these forms of rationality in order for the effect of each to be weighed. "Optimization likewise must be determined within the cognitive capacities, beliefs and goals of the organism under study" (Winterhalder and Kennett 2006a).

2.3.2) Niche construction:

A second line of critique of optimal foraging models is that they depend on humans passively exploiting resources in their environment (Smith 2009). Smith (2009) argues that DBM and patch choice models assume that humans do not manipulate patches of resources to increase their productivity. Smith lists many examples of societies where foragers will manipulate the distribution and growing environment of plant and animal resources to improve their productivity. Smith (In Review) gives, for instance, the example of the Owens valley Paiute groups in the Great Basin area who engaged in modification of the landscape to expand and enhance wild tuber production via irrigation and soil tilling. Recently Zeder (2012) has critiqued the assumption that diversification and intensification of resources only occurs in contexts of resource depletion (one of the assumptions of a specific component of OFT: Broad Spectrum Theory) and argues that social and economic goals can also drive improvements in foraging and in cropping systems.

Smith (2009) argues that humans are the ultimate "ecosystem engineers" and that Niche Construction Theory helps explain these conceptual flaws by recognizing that hunter-gatherers play an active role in modifying their environments. Niche construction is the process whereby organisms modify niches through their activities and choices (Odling-Smee, et al. 2003). The idea of niche construction was introduced to evolutionary biology and ecology in during the 1980s (Lewontin 1982, 1983) to address the fact that human beings, like many other organisms, do not only adapt to the environment but also adapt the environment to their own goals, making choices or adapting behavior to create "niches. " Because of their capacity for culture, i.e., the

ability to acquire and transmit learned knowledge, beliefs, and skills in order to devise more efficient solutions problems, humans are adept at constructing their own niches (Laland and Brown 2006).

Niche construction's contribution to thinking about human exploitation of food resources is crucial. In particular, ideas relating to niche construction can be factored into behavioral ecology models by accounting for labor costs in diet breadth or Z score models. They can also be factored into patch choice by accounting for increased production in patches manipulated by humans.

HBE models explicitly evaluate the variables that influence how humans go about selecting their food resources. These models are constructed based on the assumption that humans will act in a way that optimizes overall caloric return. I argue that more important than creating models that predict what an optimal strategy would be, it is necessary to create models that first help us outline the limits of the possible: parameters that are not always understood for the past. By first outlining the limits of the possible or the constraints affecting human behavior, we move to the next step of inference on Platt's (1964) tree of learning. By modeling these constraints one can clarify verbal desriptions of nature and the mechanisms that may have constrained or favored the adoption of certain subsistence strategies in the past. This formulation can aid researchers in identifying important parameters and can help the researcher identify the processes involved in subsistence change. Such an approach can also address some of the critiques of niche construction, by identifying the parameters of environmental niches that humans would have had to have modified in order to carry out their subsistence practices.

In this sense, the creation of models has the potential to reveal cultural characteristics or values that may have been otherwise overlooked. By first eliminating explanations based on biological and environmental constraints, the set of models I employ can lend solid support to the cultural interpretations of human behavior, as all other options have been explicitly eliminated.

2.4) Applications of HBE to Archaeology

Optimization models have been applied to a number of case studies to understand changes in human subsistence regimes. Behavioral ecology has for the most part been applied to ethnographic studies of foraging populations (Ames 1995; Bailey and Headland 1991; Binford 1978, 1983; Hart and Hart 1986; Kelly 1995; Speth and Spielman 1983). Ethnographic studies are well suited for testing optimal foraging models as detailed quantitative data on day-to-day subsistence can be collected and compared to predictions.

Applying optimization models to archaeological situations can be difficult, as taphonomic processes restrict the available data, making the testing and evaluation of such models challenging. A primary complication arises from the fact that the archaeological record is by nature fragmentary. Unlike ethnographers, archaeologists cannot directly observe day-to-day behavior. In particular, paleoethnobotanical studies are poorly adapted to informing us about the actual percentage of different foods in the diet, as some foods such as tubers do not preserve (or preserve in forms that are otherwise unquantifiable such as starch grains). Because of the vagaries of taphonomic processes, models created for ancient peoples can never be fully tested. Gremillion (In Review) has pointed out: "One of the key benefits of the modeling strategy is especially challenging for archaeologists, namely the exploration of mismatches between model

and data as a way to isolate and probe important relationships between variables". As a result, it can be difficult to determine why predictions fail because there are so many parameters in archaeology that cannot be fully evaluated for lack of evidence (Gremillion 2002). In addition, foraging models predict individual decisions, whereas the archaeological record is representative of decisions made over a series of decades or sometimes even hundreds of years (Grayson and Delpech 1998).

A complication with the application of HBE models to paleoethnobotanical data comes from the fact that it is difficult to model food quantities or relative importance in the diet. Plants vary widely in the production of plant parts used as food (such as seeds, tubers, etc.) and many of these parts do not survive in the archaeological record. For this reason, better uses of HBE models have been developed in zooarchaeology, where estimates of animal body size and weight as well as methods such as MNI (Minimum Number of Individuals) can be used to understand their contribution to the diet, although these methods of quantification are also problematic in many cases (Bird, et al. 2002; Broughton 1994a, b; Grayson and Cannon 1999; Stiner and Munro 2002; Stiner, et al. 2000). I argue that HBE models can still, however, be useful as heuristic devices, interpretative tools, and as ways of organizing thinking about ancient subsistence practices. I present examples of some successful applications of HBE models to archaeology and demonstrate that, in most of these cases, the authors were not able to construct a full test of a HBE model. I finish by arguing that it is first necessary to construct models that are capable of dealing with the constraints faced by ancient agriculturalists if we are to understand how and why humans adapted and invested in their agricultural systems during the spread of agriculture.

2.4.1) Applications to the study of ancient agriculture:

Because of their utility in helping predict changes in food procurement among foragers, an HBE approach has been useful in helping us understand how foragers move from a food collection to a food production context. These methods have thus increasingly been used to illuminate the factors that may have led to the transition to agriculture (Gremillion 1996; Keegan 1986; Piperno and Pearsall 1998; Terrell, et al. 2003; Winterhalder 1990; Winterhalder and Goland 1997).

Human behavioral ecology models have been applied to studies of the origins of agriculture in several ways. Several authors have tried using HBE models (such as the Diet Breadth Model) to predict optimal strategies of acquiring plant resources. Piperno et al. (2006a; Piperno and Pearsall 1998) have used DBM models as a heuristic device to explain the move towards exploitation of tuber crops in the lowland neotropics. They argue that climatic changes at the Pleistocene-Holocene transition led to the expansion of rainforests into areas previously occupied by openland vegetation. Although tropical forests are rich in biodiversity, it has been argued in numerous instances (Bailey, et al. 1989) that tropical forests lack foods high in carbohydrates (namely tubers), and that species that do contain carbohydrates are widely dispersed, meaning that travel times to acquire them are long and costly (Bailey, et al. 1989: 60-61). Most of the foods available for human consumption are situated high in the canopy and thus are out of the reach of humans. The savannah-scrub on the other hand provided easily accessible and ample calories for foragers in the form of large game. Piperno et al. (Piperno 2006a; Piperno and Pearsall 1998) argue that the decrease in size of the calorie rich savannah-scrub habitat led to the replacement of these high ranked resources with foods that may have previously been

ignored, such as grain crops and tubers. In these studies, Piperno and Pearsall (1998) use a diet breadth model as an interpretative framework and heuristic device, but no modeling takes place.

Gremillion (1996; 1998) has used DBM to examine the rise of seed crop cultivation in the eastern United States around 3500 BP. In her examination of the archaeological evidence, Gremillion tried to understand why the consumption of small seeded plants such as *Chenopodium*, marshelder, and maygrass became popular in an environment dominated by high-rank resources such as hickory, oaks, chestnut, butternut and walnut. She argues that ecological changes in forest composition and the easy storage of these smaller seeded species through the winter could have contributed to their inclusion in the diet (Gremillion 2004). In her case studies, Gremillion uses harvest rates and harvest costs to rank her resources in terms of return rates (using kcal/hr as currency). This calculation is carried out for each crop. The second part of the diet breadth model, namely, the part that helps decide at which point resources should be dropped out of diet and replaced by others, is not employed by Gremillion in her study.

When dealing with domesticated crops, creating a DBM becomes more complicated because of the delayed returns associated with agriculture. In a study of the adoption of agriculture among the Fremont, Barlow (2002, 2006) compares the returns acquired from maize agriculture and foraging scenarios. She reasons that if the marginal value of one hour farming is greater than that of foraging that foragers should begin farming to optimize their caloric intake. Her study uses a DBM to explain why agriculture was taken up only on a sporadic basis in the Great Basin. Barlow (1997; 2006) uses estimates of kcal returns for foraging for different wild foods based on experimental and ethnographic data. She calculates returns for farming using reconstructed data

for maize yields in the region and calculates the time spent per hectare, planting, caring for and processing a crop. (Maize is a crop that has been particularly well studied from an ethnographic standpoint.) She compares the kcal per hectare (on a yearly basis) to these estimates of foraging for other foods. Because of the high labor investment required by maize agriculture, it became profitable for foragers to practice agriculture only in times when foraged resources were depressed.

Archaeologists are plagued by a lack of data on the total spectrum of available foods, and as a result it has been difficult to apply DBM models to questions like the origins of agriculture. Only the foods that were consumed by foragers have a high probability of being discarded and entering the archaeological site. The foods that were not high ranking or that were ignored are rarely found in archaeological deposits, making it difficult to construct a full list of possible options against which to test the model.

HBE models have also been applied to the movement of domesticates around the world. Gremillion (1996) uses the concepts of risk, diet breadth and opportunity costs to predict the introduction of foreign domesticates into a hunter-gatherer diet. Using the example of the introduction of the peach and maize to the southeastern United States, Gremillion explains that the peach was rapidly adopted by hunter-gather populations in historic periods as a low cost means of reducing variance, which she demonstrates using a combination of a z-score and a diet breadth model.

When examining the spread of agriculture to Valencia in Spain, McClure et al. (2009) use a model of ideal free distribution (IDF) to indentify how subsistence strategies, herd use and land use are tied together. An IDF defines different habitats in which both (population) density-dependent and independent factors help determine a habitat's suitability. A habitat's suitability is defined when population density is close to zero. The suitability of the habitat can change as the number of individuals that exploit it increase. Declines in suitability can result from reduction of resources, competition or environmental degradation. In some circumstances, populations may also increase a landscapes' suitability. Using an IDF as a heuristic device, McClure et al. (2009) argue that during the initial phases of the Neolithic, moving agriculturalists farmed patches intensively until their productivity declined and then moved elsewhere. Animal husbandry was also practiced in patches that were not otherwise suitable for agriculture, thus increasing productivity. They argue that this strategy led, however, to rapid landscape erosion, and as a result populations began to exploit previously wooded environments and to cut down trees along river valleys. To ensure their meat returns, transhumant pastoralism was introduced with animals being sent out to pasture further from agricultural settlements.

Marston (2011) has also used the Z-score model to analyze changes in risk management in the subsistence patterns of the site of Gordion in Turkey. He used this model to demonstrate that diversification and intensification of crops were strategies employed by the inhabitants of the site to reduce risk. To do so, Marston (2010) does not formally construct a test of an HBE model, but uses the concept of risk as a heuristic device and uses proportions of different crops as an indicator of the risk management strategies employed by the inhabitants. Marston (2010; 2011) lists several ways in which agriculturalists can protect themselves against risk; The first of these

falls under the category of diversification. Agriculturalists can use strategies of either *temporal diversification* (double or triple cropping) or *spatial diversification* (which can be affected by mobility, by expanding into or exploiting different ecosystems, and/or by sharing production). Agriculturalists can also deal with risk by intensifying their systems of production. This can be achieved through irrigation and water management or by overproduction, whereby amounts of agricultural produce beyond normal needs are obtained and are kept through storage.

In most of the examples outlined above, formal tests of the HBE models and the optimality assumption are not tested, primarily because of a lack of suitable input data, whether it be in terms of return rates or archaeological data for a species use.

2.5) Using modeling to understand the spread of agriculture

Aside from using a modeling approach based on optimization, I argue that models are generally useful for understanding the spread of agriculture.

HBE models provide a useful framework for inspiration as they explicitly acknowledge the variables that affect the decision to incorporate a given resource into the diet (plant ecology, processing time, search time, cultural choice). An approach focused on identifying the constraints faced by ancient agriculturalists can help to identify the factors that drove innovation and adaptations in ancient agricultural strategies. By documenting agricultural practice from the "bottom-up," this approach has enabled me to make more accurate distinctions between the various agricultural strategies employed by farmers involved in increasingly complex social and economic networks (Erickson 2006).

That said, current behavioral ecology models, such as the diet breadth model (MacArthur and Pianka 1966; Stiner and Munro 2002) and patch choice models (Charnov 1976; Stephens and Krebs 1986) are not well adapted for use in agricultural societies for several reasons. Firstly, they assume that humans are mobile and can relocate to areas of greater plant or animal resources. Unlike humans and animals, plants are sessile and are not capable of relocating to optimal conditions during the course of their lifetime. The niches they occupy are determined by tightly constrained ecological conditions. Therefore, when human subsistence begins to be based on the farming of these sessile organisms, the assumption of humans being able to map onto their food source becomes no longer valid. By choosing to intensively exploit a patch through practicing agriculture, humans become tied to their patches. As they move into new areas and create new patches under conditions in which they are sedentary for long periods of time, they need to adapt their strategies to either fit the ecological conditions provided by this patch or to modify the patch itself. Once agriculture and a sedentary lifestyle have been established, it is imperative that agriculturalists carry out farming in areas where the life cycle of their crop plants can be sustained or where an artificial niche can be constructed that allows the plant to complete its lifecycle.

New sets of assumptions are needed when trying to understand how humans adapted their agricultural strategies during the spread of agriculture. First, as humans move into new environments they need to adopt strategies that allow them to exploit new niches. In an agricultural society, this necessarily involves changing their agricultural systems to one that can be sustained in a given ecological niche. Thus before asking how humans optimize agricultural

systems, it is imperative to first ask: how can humans ensure that they are able to carry out agriculture at all? I argue that a first level of useful modeling should be one that focuses on outlining the series of constraints associated with practicing agriculture in the different environmental settings into which humans moved with their domesticated plants.

Humans can respond to constraints in a variety of different ways. A basic strategy can be changing crop repertoires and planting the types of crops that are able to reach maturity in the ecological conditions humans have moved into.

As Marston (2011) has pointed out, other strategies can involve risk management such as diversification or intensification in order to minimize the chance of loss or of subsistence failure. This can also be achieved by modifying the niche itself to fit the ecological requirements of the plant, such as by supplying water via irrigation systems. Changes can also be made to the growing requirements of the plants, e.g., by practicing indoor propagation of seedlings to shorten the growth season needed outdoors or by breeding cold or arid adapted varieties. In order to assess what the limiting factors were to farmers moving agricultural products to new niches, it is essential to model the biological characteristics of the crops grown by humans and to determine their niches (or the limits of the conditions that are able to sustain their growth).

Ranking resources into a DBM model can also be complicated, since accurate return data can sometimes be difficult to acquire for agricultural societies. Crop yields and the ability to grow crops can vary widely according to local ecological conditions. Crop productivity can also vary widely between geographic locales due to local soil, temperature or water conditions. Trying to

estimate the returns of a crop in kcal/hr is difficult because time and labor inputs can be highly variable according to local environmental conditions. For example, in some regions rice may be grown on flood plains or in low lying flooded fields that require relatively little labor investment. In other regions, the building of terraced paddies can require substantial labor and technological investment. Measures of kcal/hr are easy to estimate in foraging situations as returns can be calculated almost immediately. With some exceptions, processing time generally happens soon after search time. However, in agricultural situations, there are long delays between labor input (the equivalent of search time) and returns, making it difficult to calculate kcal per hour and rank resources in a DBM type model.

In most cases, many months elapse between planting crops and the harvest. During this time there can be various amounts of labor input. Daily field labor can also be difficult to account for. For instance, some fields require relatively little weeding or care, whereas others can require a substantial investment. When fields change from being rain or flood bank fed to being irrigated, the construction and maintenance of canals and structures must also be factored into the picture. However, here additional complications arise, as the construction of canals can be a labor investment that lasts for many millennia. It is, however, worth noting that cancals require maintenance on a seasonal or yearly basis.

An additional major difference exists in the accounting for labor costs. In foraging societies search time and handling time are activities that can only be carried out for one resource at a time. A decision to take one resource instead of another will result in an opportunity cost. However in agricultural societies, specialization of the labor force has generally already occurred, and

opportunity cost is no longer an issue. In addition, because returns from crops are delayed in agricultural societies, and farmers do not need to be actively involved in their care or collection for entirety of the day, other activities can be undertaken. Opportunity costs thus function very differently in agricultural and non-agricultural societies.

I use modeling to clarify the processes underlying the spread of agriculture by identifying the series of constraints faced by the ancient agriculturalists that moved into new territory:

a.) The first part of my model analyzes the biological and ecological constraints associated with practicing a given crop, using methods derived from ecological niche modeling. This first part of the model allows me to answer the simple question of whether or not a given niche contains suitable conditions for the growth of a given crop. This first part of the model asks a simpler question than most optimal foraging models. Rather than trying to demonstrate whether or not humans behaved in an economically rational manner, it first seeks to outline the constraints of what is, and what is not possible.

b.) Even though the basic conditions for a crop's growth may be met in a given locale, this does not necessarily mean that this crop can be grown without a high degree of failure. The second part of my model thus uses climate data to calculate the risk associated with practicing a given crop (i.e., if a crop could be grown in X locale, how often would crop failure occur given current climatic data, i.e., what was the chance of loss).

c.) As calculating the amount of labor time put into growing different crops can be difficult, I rank crops according to the level of intensity their cultivation requires. For example terraced paddies, flood plain paddies, rain fed fields, etc.

By so doing, this model allows me to understand the constraints faced by early farmers as they moved into the highly orographically defined environment of Southwest China. I am then able to compare the predictions from these models to archaeobotanical data derived from early sedentary populations in the region to understand how these constraints shaped human choices regarding subsistence practice in this area in the past.

Summary

Abundant data and good chronological resolution mean that approaches to the spread of agriculture in other areas of the world, like Europe, have been able to begin to answer questions about the identity of the movers of agricultural products. I argue that in southwest China, the lack of archaeological investigations in this region as a whole means that answering such questions are premature. However, in recent years and through the work presented in this dissertation, I argue that increasing amounts of archaeobotanical and zooarchaeological data mean that we can begin to understand how this spread occurred. To do so, I adopt an approach that focuses on identifying behavioral responses to new ecological niches and climatic conditions during agriculture's spread.

Human behavioral ecology is one area where anthropologists have worked to indentify behavioral changes in human subsistence patterns. In recent years this approach has been applied to a number of archaeological studies, primarily those relating to the transition to agriculture. I argue, that traditional HBE models are inadequate for the study of agricultural societies on

several levels and propose that an approach based broadly in HBE but informed by ecological niche modeling can help us understand how agricultural societies adapted their subsistence regimes. Finally, I propose a three-step model that allows me to understand the ecological, biological and other constraints that the growing of different crops entailed in this region.

CHAPTER THREE

METHODS

Maps of the ecological niches exploited by the inhabitants of Southwest China and of the niches that the crops grown in this region could occupy provide necessary background for interpreting human behavior in the region. Creating these maps requires data on the biological and physical requirements of the crops involved and climate data to map how the requirements needed to grow the crops are distributed across space. By drawing these data into species distribution models derived from the field of ecological niche modeling, constraints on plant growth can be outlined. In addition, direct evidence for past economic behavior requires extracting, sorting and analyzing archaeobotanical data against which ecological niche models are tested. This chapter outlines the methods employed to obtain both sets of data.

3.1.) Outlining the series of constraints: Ecological Niche Modeling

In order to determine the ability of ancient agriculturalists to grow a given crop, it is essential to first consider the biological constraints of the crop and of the ecological niche into which it is being moved. The field of ecological niche modeling provides the tools to outline these constraints. Understanding the distribution of species in the environment has always been a central issue in ecology (Chase and Leibold 2003; Towsend, et al. 2011), and the importance of climate, particularly temperature, for determining the distribution of different plant species has been recognized for many years (Parker 1963). Quantifying the relationship between climate and species distribution has been an important focus of ecological niche modeling. Furthermore, species distribution models have become increasingly used in ecology as a means of predicting

shifts in the range of species as a result of climate change (Guisan and Thuiller 2005; Guisan and Zimmermann 2000; Thomas, et al. 2004).

Understanding the distribution of species has a number of different applications and has been used as tool to assess the impact of change in land use and climate on species distribution, to set up conservation priorities, or to improve floral and faunal atlases. In archaeology, ecological niche modeling has been used to understand the spatial extent that humans (Banks, d'Errico, Peterson, Vanhaeren, et al. 2008) and the animals they consumed (Banks, d'Errico, Peterson, Kageyama, et al. 2008; Polly and Eronen 2011) could occupy during the Pleistocene in Europe. Preliminary analyses combining site distribution data and paleoclimate reconstruction have also been carried out for Clovis sites in the United States by the same group (Banks, et al. 2006; Gillam, et al. 2007).

Mapping the thermal niche of crops has also been of great interest to modern agronomists as it allows them to determine the limits of crop growth (Hodges 1990; Jones 1992; Parry 1985). In addition to informing us about the constraints facing modern farmers, these models can also be applied to the past. Creating visual map outputs of these models has improved greatly in the past few years by advances in GIS software (Kearney 2006).

In ecology, a niche is the sum of habitat requirements that allow an organism to persist and produce offspring. The niche, a “set of conditions within which an organism can survive and persist”(Hutchinson 1957), can be thought of in two different ways:

a.) *Fundamental niche*: "The fundamental niche may be thought of as an '*n*-dimensional hypervolume,' every point in which corresponds to a state of the environment that would permit the species to exist indefinitely. It is the axes of this *n*-dimensional hypervolume that define environmental space" (Hutchinson, 1957: 416). An organism free of interaction with other species can use the full range of biotic and abiotic conditions in this niche. As our model deals with agriculture, we take the fundamental niche to mean the space the organism could occupy, if the environment were not modified by human activities and no other organisms were competing for resources. The fundamental niche is theoretical as no species exist in complete isolation.

b.) Because of interspecies competition or other factors, organisms often occupy a much narrower part of their niche. This *realized niche,* represents the actual extent of the species. Unlike species growing in the wild where competition can limit the realized niche, when dealing with crop plants, the extent of the realized niche can often be increased beyond the boundaries of the original fundamental niche, because of niche construction, or modification of the environment, or the removal of competitors to extend the conditions necessary for the growth of a species. Humans can modify not only the niche, but can modify the genetics of the plant itself, by selecting for crops that are tolerant to aridity, cold and that have shorter growing seasons.

c.) When environmental conditions encapsulated within the fundamental niche are plotted in geographical space this gives us the *potential distribution* of a species.

Ecological niche modeling uses species distribution models to determine an organism's potential distribution. Several different types of models can be used to determine the distribution of a species across the landscape. These include *correlative* or *mechanistic* models.

A.) *Correlative* models aim to estimate the distribution of species based on known distributions with suites of environmental factors that could influence their distribution. "These correlative species distribution models (SDMs) require little knowledge of the mechanistic links between organisms and their environments, which is often an advantage for poorly studied taxa" (Kearney and Porter 2009). Correlative models employ geo-referenced locality records for species, whose presence or abundance of species suggests that individuals were able to develop, survive to the adult stage and reproduce in that location (Pearson 2007). These data are correlated with a suite of abiotic factors such as temperature, soil conditions, sunlight and the presence or absence of other species used as food or shelter. These factors are referred to be within the species tolerance range. Correlative models cannot however, establish a direct causal relationship with a given variable. Correlation of a species with a given variable may be the result of an indirect effect, or this variable may be associated with another variable that was absent from the model (Mac Nally 2000). In this sense correlative species distribution models do not always reflect a mapping of the fundamental niche to the landscape (Kearney 2006; Pearson and Dawson 2003).

An agricultural crop's present day distribution may not be informative of past distribution as it can be influenced by a variety of factors, including improvements in technology (such as the ability to created terraced paddies for rice, the ability to pump water though canals), or in cultivar

variety (i.e, the development of short season or aridity tolerant cultivars). Correlative models are not adapted for the purposes of investigating past crop ranges.

B.) *Mechanistic* models do not employ current maps of species distribution, but rather incorporate physiologically limiting mechanisms in a species tolerance to environmental conditions (Kearney and Porter 2009). In other words, they take the known ranges on physiological conditions within which an organism can survive and create models and maps based on these conditions. This can include responses to environmental conditions like temperature, precipitation, frost injury, etc. It can also include measures such as competition with other species. These mechanistic models require a detailed understanding of the physiological response of species to environmental factors and often can only be used for species of which the physiology and distribution is very well understood. The challenge with mechanistic models is to translate the interaction of an organism with its environment into key fitness components. These generally include measures of survival, performance, development, growth and reproductive capacity.

Once these factors have been identified and quantified, we are then given a description of the species *fundamental niche* that can then be mapped onto the landscape to infer its *potential distribution*. The potential distribution is determined through a process of elimination, whereby areas determined as being outside the organism's niche are progressively discarded.

In mechanistic modeling, the species enters the model not as a point on the map, but rather as a series of morphological and physiological traits. One can, for instance, model the thermal niche of an organism. An example of this is how Buckley et al. (2010) used a biophysical threshold

model to determine the distribution of a species of lizards. In this model, they calculated the degree days required for the completion of two life generations to determine the range limit of lizards and mapped these thermal niches onto current geographic conditions.

A major disadvantage of mechanistic models is that they often require more time and data to construct and validate than correlative models. There are many circumstances, however, where mechanistic approaches are preferable and therefore worth the investment of time and resources. A good comparison of mechanistic vs. correlative models can be found in Kearney and Porter's (2009) work. In our case, correlative models cannot be used, as the present distribution of agricultural species is hugely different from their past distribution due to massive advances have been made in agricultural technology, landscape modification, and genetic selection of crops. Correlative models made using archaeological data on the distribution of crops can also be problematic as a crop's range may have changed throughout time and the products of agriculture can enter the archaeological record through trade in locales where they were not previously grown.

While correlative species distribution models are also very useful for developing hypotheses about range constraints, mechanistic models provide more focused and detailed hypotheses through explicitly identifying a limiting process. Mechanistic models can also be useful for revealing the factors that limit a species range. To determine the potential niche of the different crops exploited by early agriculturalists in Southwest China, I use a mechanistic model to predict their thermal niche.

3.1.1) Physiology and Plant Phenology

Before looking at ways of mapping the thermal niches of crops, I briefly review the factors affecting crop growth. The field of physiological ecology or phenology helps us determine the physiological limitations of organisms and the constraints the environment has on their abundance (Jones 1992). The term phenology is used to define the relationship between periodic biological events in an organism's life cycle and the climate in which they live. In plants, three main stages of the life cycle are important to describing their development: the vegetative period, flowering or reproductive period, and grain filling or ripening period. More detailed breakdowns of the stages of plant growth have been described by (Hodges 1990; Jones 1992).

Environmental variables affecting plant growth may comprise either continuous data (data that can take any value within a certain range, such as temperature or precipitation) or categorical data (data that are split into discrete categories, such as land cover
type or soil type). A summary of the different types of variables affecting plant distribution is presented in the Figure 3.1 below:

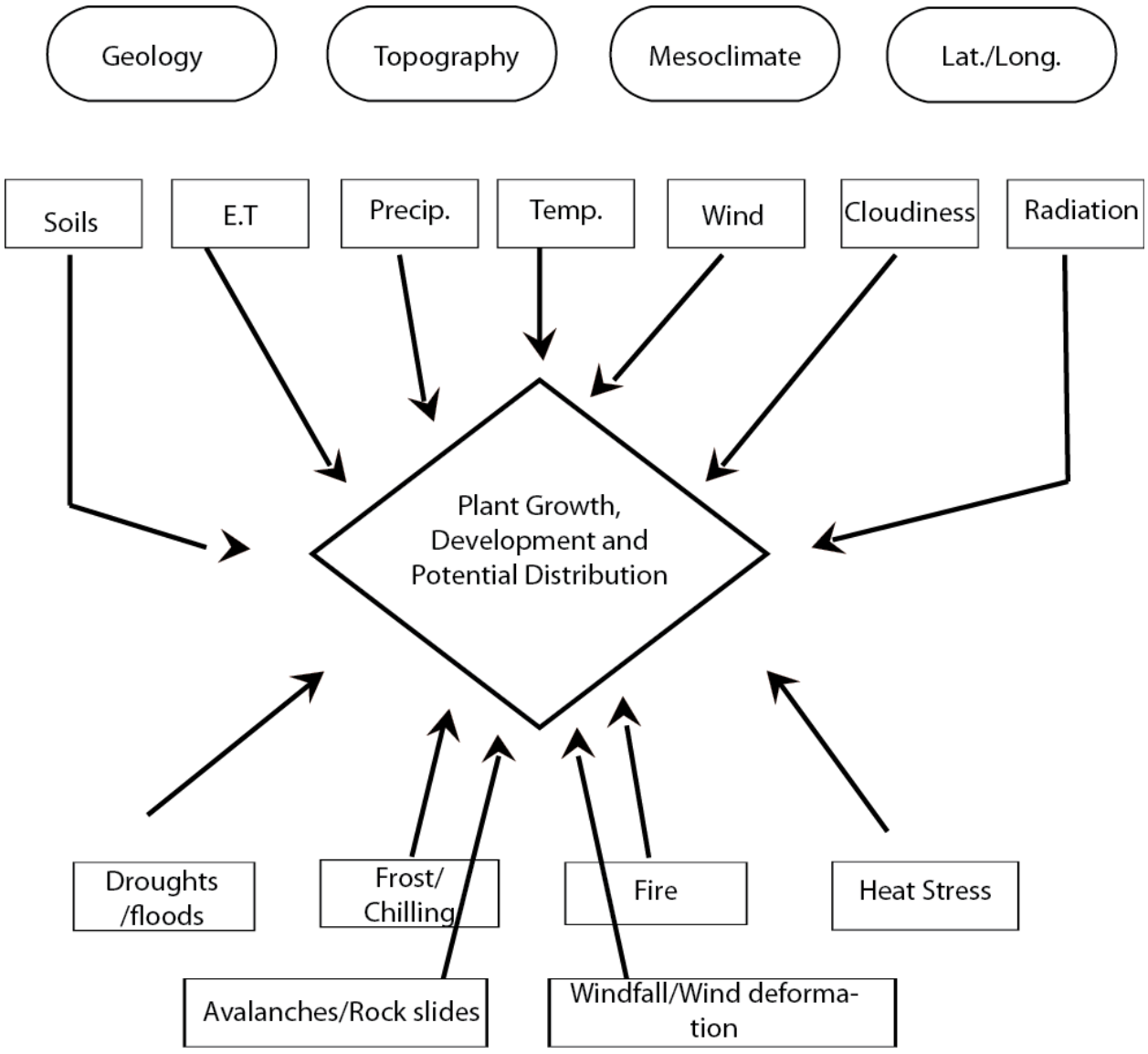

Figure 3.1 Environmental Variables affecting plant growth (modified after AIACC 2005: Figure 1).

As is summarized in Figure 3.1, there are a number of key abiotic factors involved in plant growth and development. Several main factors are essential: nutrients, soil, air (CO_2), sunlight for photosynthesis, and sufficient temperatures for maintaining life. Of these, only CO_2 levels are

relatively constant across the globe and do not require additional modeling. I review a few of the factors that affect plant growth here.

1.) Day length (photoperiod) is important for determining the flowering of plants. Many flowering plants use a photoreceptor protein to sense seasonal changes in night length, which are taken as signals to flower. Plants that exhibit *obligate* photo-periodism require a long or a short enough night before they will flower. However, plants that exhibit *facultative* photo-periodism will have a higher likelihood of flowering under appropriate light conditions, but will eventually flower regardless of night length. Plants can be further classified as *short-day plants* and *long-day plants*. A long-day plant flowers when the day length exceeds their critical photoperiod. Examples of crops that are long day plants include wheat, oats and barley. Both wheat and barley are long day facultative plants, whereas oats are long day obligate plants. A short-day plant flowers when day lengths are less than their critical period. These plants require a long period of uninterrupted darkness before floral development can begin. These plants generally tend to flower towards the end of the summer or fall when days grow shorter and nights grow longer. Some short day obligate cultivars are tobacco and maize, whereas short day facultative cultivars include rice, cotton, hemp and sugar cane (Raven 2009). Other factors such as solar radiation, precipitation and water, soil quality and nutrients also have important effects on plant growth.

2.) Temperature has a profound effect on plant growth at a number of different stages of plant development and I primarily consider the effects of temperature on plant growth in the analysis carried out in this dissertation. Temperature effects germination, growth, flowering and seed filling. Both germination and growth fall under the category of vegetative growth.

a. Germination: Temperature is an essential factor for plant germination. Different species have different temperature ranges within which germination will occur. Trying to germinate seeds in conditions below or above this range will lead to non-germination. In the spring, cool soil temperatures can be a limiting factor for germination rates (Raven 2009).

b. Temperature also plays an important role in vegetative growth. Within limits, rates of photosynthesis and respiration in plants rise. As temperatures reach the upper growing limit of the crop, the rate of food used by respiration may exceed the rate at which food is manufactured by photosynthesis. Thermoperiod refers to daily temperature change. Plants produce maximum growth when exposed to a day temperature that is about 10 to 15°F higher than the night temperature. This allows the plant to photosynthesize (build up) and respire (break down) during an optimum daytime temperature, and to lower the rate of respiration during a cooler night (Raven 2009).

c.) Temperature can also play a critical role in flowering, therefore seed and fruit set and development. Temperatures that are too high or too low can prevent fruit set and development. However in certain cases, plants require a number of days of low temperature to grow properly. This vernalization requirement is true of crops growing in cold regions. For instance, apples and peaches require 700-1000 hours below 45°F (7°C) before they break their rest period. If this cold requirement is not met then fruit will not be set properly. Flowering and grain filling are important phenological stages to consider in plant development (Raven 2009).

It is essential to consider temperature differences between ecological settings when thinking about the potential for crop success. The length of the growing season is determined by the dates

of arrival and end of satisfactory condition for growth. This is generally determined by the arrival of temperatures necessary for plant germination, and for maintaining the growth of delicate seedlings. Once the plant has reached maturity it is essential that satisfactory temperatures persist for long enough for the plant to set seed or fruit and for that seed or fruit to reach maturity. Many crops are not frost tolerant and, for the majority of crop plants, the dates of last and first frost establish the limits of growing season length. Even more than growing season, it is important to establish that a sufficient amount of units of heat are present in order for a crop to achieve maturity.

3.1.2) Growing Degree Day Analysis

Given the limitations of archaeological data, it is difficult to control for variables other than temperature. I therefore decided to examine the effect of temperature as a result of geographic location on the choice of which crop to plant.

In ecology, the concept of GDD (Growing Degree Day) is used as a measure of heat accumulation to predict plant development rates. GDD assumes that

1.) There is a base temperature (T*base*) under which an organism grows very slowly or growth halts. It is important to gain an accurate understanding of the base temperature of growth for each crop. Different crops have different baseline temperatures. For instance, while wheat, barley and rye have a baseline temperature of 5.5 °C, rice and maize have a baseline temperature of 10° C.

2.) The growth rate increases with temperature above the base temperature.

3.) Growth and development are closely related to daily temperature mean accumulations above the base temperature.

4.) There is a temperature above which plant growth does not increase (an upper threshold). For most species this is 30 °C. However, some warm temperate and tropical plants do have significant requirements for days above 30 °C to mature fruit or seeds. For instance, rice requires that the upper threshold be set at 35 °C.

Growing degrees days are calculated for each individual day as the maximum plus the minimum temperature divided by 2 (or the mean temperature) minus the base temperature. Accumulated growing degree days are calculated for a given period of time by adding each day's GD contribution. It is possible to calculate cumulative growing degree days as the sum of days with temperatures above the base temperature (T*base*) over the entire year. This assumes that the temperatures after the end of the growing season will be lower than *Tbase*, which is not the case for all regions. Thus in some instances, it is suggested that one begins to calculate cumulative GDD at the start of the growing season (date of last frost) and stop calculating at the date of first frost. When I calculated GDD using both methods, I found that only minor differences exist in the data and decided to calculate a yearly GDD as a result, except for certain crops that grow over the winter (winter varieties of wheat and barley).

There are several different methods for calculating growing degree days. These include

a.) A Simple Method:

This method compares the daily mean temperature (*Tmean*) to the base temperature. The daily mean temperature is the average of the daily maximum and minimum temperatures. If this

average is greater than the threshold temperature, the GDD accumulated for that day is the threshold temperature subtracted from the daily mean temperature. If the daily mean temperature is less than the base temperature, then the GDD for that day is zero. This is calculated using the following formula:

$$GDD=[(T_{max}+T_{min})/2]-T_{base}$$

From this equation, a cumulative GDD is calculated, from the start of the arrival of days that have a GDD above zero. From this point, an accumulative GDD is calculated by adding the GDD's until the conditions return to zero.

b.) Modified Growing Degree Days:

A modified method, sets both an upper and a lower threshold for temperature. Typically 30 degrees Celsius is used as the upper threshold. If the daily minimum temperature is below the threshold then it is set to the lower threshold temperature. These modified temperatures are then averaged and compared to the base temperature in the same way as the formula above. This uses the following formula:

$$Degree\ days = [(upper\ threshold\ (or\ T_{max}) + T_{base}\ (or\ T_{min}) / 2)] - T_{base}$$

c.) Sine Wave Method:

The Sine wave method is one of the most accurate methods of calculating the GDD as it takes into account the rate of plant growth at different temperatures. Daily temperature patterns closely resemble a sine wave function and this method determines the amount of degree-days by calculating the amount of area under the temperature curve and above the base temperature. Another way of using a sine way model involves plotting temperature against plant rates of development, however to do so a very detailed knowledge of plant growth patterns is required. In this kind of model, a graph is made where the rate of development is plotted on the y-axis (1/time) and the temperature is plotted on the x-axis (Allen 1976).

d.) Yearly Average Method:

The interest in looking at global differences in agricultural production has led some authors to create global maps of growing degree days. In Licker et al (2010), GDD is calculated on a global level in order to outline the reasons underlying gaps in agricultural yield around the world. Projects that carry out this kind of analysis on a global level, use a method for calculating growing degree days described by Ramankutty et al. (2002) Ramankutty et al. (2002) calculate growing degree days as an annual sum of daily mean temperatures over the base temperature using the following formula.

$$\mathrm{GDD} = \sum_{i=1}^{365} \max(0, T_i - T_b)\,\mathrm{days} - \mathrm{degrees}$$

Where T_i is the temperature in C at each time step, and T_b represents the base temperature.

Horticulturalists calculate how many cumulative GDD's are required for a crop to achieve maturity. In recent years, growing degree days have been used by ecologists to calculate the

"climatic potential yield" of different crops. Actual yield values for 18 of the world's most dominant crops were compared within regions of similar growing degree days to identify areas of the world where yield gaps exist (Licker, et al. 2010; Monfreda, et al. 2008).

More recently there have also been archaeological applications of the use of growing degree days to understand past patterns of crop use. This work has principally been carried out in the American Southwest on maize agriculture in Colorado and New Mexico (Benson 2011). Here, the high resolution of historical climate data and data on soil quality meant that the authors were able to carry out high resolution modeling of how changing climate affected pre-historic crop yields during the 12th-13th century AD. A paper in draft format also explores these issues on a continental level for North America as a whole (Bockinsky and Kohler 2012).

3.1.3) Calculating Growing Degree days for Southwest China

For many of the species of domesticates used in Southwest China, there are very few studies looking at the hourly responses of plant growth to different temperatures. As a result, I could not use the more accurate Sine Wave method of calculating growing degree days. In addition, I decided that the yearly average method would not provide an accurate enough estimation, as it was not capable of capturing seasonal variations. I thus decided to use the modified method of growing degree days and set the maximum temperature threshold at 30 °C for all domesticates except rice that was set at a 35°C threshold (see reasons for this in Chapter 5). The base temperature was different according to which crop was being examined and we used base temperatures of 5.5° C (for wheat, barley, foxtail and broomcorn millet) and 10° C for rice.

The modified GDD values were calculated in Microsoft Excel using the following IF/AND command line:

*IF(AND(Temp Max<=Base temp, Temp Min<=Base Temp),0,IF(AND(Temp Min<=Base Temp, AND(Base Temp<Temp Max, Temp Max<=Max Threshold)),(Temp Max+ Base Temp)/2-Base Temp, IF(AND(Temp Min<=Base Temp, Temp Max>Max Threshold),(Base Temp +Max Threshold)/2-Base temp, IF(AND(AND(Base Temp<=Temp Min, Temp Min<Max Threshold),AND(Base Temp <=Temp Max, Temp Max<=Max Threshold)),(Temp Min+ Temp Max)/2-Base Temp, IF(AND(AND(Base Temp<Temp Min, Temp Min<=Max Threshold),Temp Max>Max Threshold),(Temp Min+ Max Threshold)/2-Base Temp, IF(AND(Temp Min>Max Threshold, Temp Max>Max Threshold),2*Max Threshold/2-Base Temp)*

For most crops these were calculated on a yearly basis. This is because calculating the number of accumulated GDD's did not vary substantially if only calculated in between a series of given dates. I also decided to calculate these values over the course of a year as several of the species I examined had variable starts in planting dates. This however, does not work for winter varieties of wheat and barley, and in order to calculate the growing degree days available for these varieties, I set the start of the growing season in September and calculated accumulated GDD until June of the following year.

3.1.4) Accessing Climate Data for Southern China

To calculate the potential distribution for rice, foxtail and broomcorn millet, I sought to create a map that summarized the number of cumulative growing degree days across the region. In order to do so, a number of different kinds of data are required. These include daily min and max temperatures for the region. Most online sources of data only present monthly min and max temperatures. A good example of this is the data placed online at the site World Clim (Hijmans,

et al. 2005). The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km^2" resolution). Variables included are monthly total precipitation, and monthly mean, minimum (min) and maximum (max) temperature, and 19 derived bioclimatic variables (Hijmans, et al. 2005). However, no daily temperature data were available for China from publically accessible sites.

It was impossible to retrieve records of daily min and max temperatures at a high spatial resolution for China and most data from local weather stations in China are restricted in access to Chinese research groups. However, daily min and max temperature data from 75 weather stations accessible to international researchers across southern China were obtained from the China Meterological Administration. I analyzed daily min and max temperatures from these 75 weather stations for the period of 1951-2011. Most weather stations in China began operating during the 1950s. Because of multiple malfunctions and gaps in the data from 1951-1954, it has been suggested that it is prudent to eliminate data from these years from any analysis (B. Liu, et al. 2004). I was left with data from 1955-2011, although some stations had less data (see Table 3.1).

Table 3.1 Coordinates of weather stations, altitude and years of coverage derived from the China Meteorological Service

Station no.	Name	Northing	Easting	Altitude (m)	Coverage
56172	Ma'erkang	3154N	10214E	2664	195304-200712
56146	Ganzi	3137N	10000E	3393	195101-200712
56182	Songpan	3239N	10334E	2850	195101-200712
56187	Wenjiang	3042N	10350E	539	200401-200712
56257	Litang	3000N	10016E	3948	195205-200712
56294	Chengdu	3040N	10401E	506	195101-200312

Table 3.1 Continued					
56462	Jiulong	2900N	10130E	7987	195207-200712
56492	Yibin	2848N	10436E	340	195101-200712
56571	Xichang	2754N	10216E	1590	195101-200712
56671	Huili	2639N	10215E	1787	195206-200712
57237	Wanyuan	3204N	10802E	674	195206-200712
57411	Nanchong	3047N	10606E	309	195101-200712
57515	Chongqing	2931N	10629E	351	195101-198612
57516	Shapingba	2935N	10628E	259	195101-200712
57633	Youyang	2850N	10846E	664	195101-200712
57707	Bijie	2718N	10517E	1510	195101-200712
57713	Zunyi	2742N	10653E	843	195101-200712
57816	Guiyang	2635N	10644E	1223	195101-200712
57902	Xingren	2526N	10511E	1378	195101-200712
56444	Deqin	2829N	09855E	3319	195308-200712
56651	Lijiang	2652N	10013E	2392	195101-200712
56739	Tengchong	2501N	09830E	1654	195101-200712
56768	Chuxiong	2501N	10132E	1772	195103-200712
56778	Kunming	2501N	10241E	1892	195101-200712
56951	Lincang	2353N	10005E	1502	195304-200712
56954	Lancang	2234N	09956E	1054	195401-200712
56964	Simao	2247N	10058E	1302	195111-200712
56985	Mengzi	2323N	10323E	1300	195101-200712
55591	Lhasa	2940N	09108E	3648	195501-200712
58027	Xuzhou	3417N	11709E	41	196001-200712
58040	Ganyu	3450N	11907E	3	195701-200712
58238	Nanjing	3200N	11848E	7	195101-200712
58251	Dongtai	3252N	12019E	4	195301-200712
58457	Hangzhou	3014N	12010E	41	195101-200712
58477	Dinghai	3002N	12206E	35	195501-200712
58633	Quzhou	2900N	11854E	82	195101-200712
58659	Wenzhou	2802N	12039E	28	195101-200106
58752	Rui'an	2747N	12039E	39	200107-200712
58102	Haozhou	3352N	11546E	37	195301-200712
58221	Bangbu	3255N	11723E	21	195109-200712
58314	Huoshan	3124N	11619E	86	195401-200712
58321	Hefei	3152N	11714E	27	195208-200712
58424	Anqing	3032N	11703E	19	195101-200712
58834	Nanping	2639N	11810E	125	195101-200712
58847	Fuzhou	2605N	11917E	84	195301-200712
58921	Yong'an	2558N	11721E	206	195101-200712
59134	Xiamen	2429N	11804E	139	195401-200712
57799	Ji'an	2703N	11455E	71	195108-200712
57993	Ganzhou	2551N	11457E	123	195101-200712

Table 3.1 Continued					
58527	Jingdezhen	2918N	11712E	61	195207-200712
58606	Nanchang	2836N	11555E	46	195101-200712
58715	Nancheng	2735N	11639E	80	195207-200712
54725	Huiminxian	3730N	11731E	11	195101-200712
57265	Laohekou	3223N	11140E	90	195101-200712
57447	Enshi	3017N	10928E	457	195101-200712
57461	Yichang	3042N	11118E	133	195108-200712
57494	Wuhan	3037N	11408E	23	195101-200712
57662	Changde	2903N	11141E	35	195101-200712
57679	Changsha	2812N	11305E	44	195101-200712
57687	Changsha 2	2813N	11255E	68	198701-200712
57745	Zhijiang	2727N	10941E	272	195101-200712
57866	Lingling	2614N	11137E	172	195101-200712
59082	Shaoguan	2441N	11336E	60	195101-200712
59287	Guangzhou	2310N	11320E	41	195107-200712
59293	Dongyuan	2348N	11444E	70	195207-200712
59316	Shantou	2324N	11641E	2	195101-200712
59501	Shanwei	2248N	11522E	17	195208-200712
59663	Yangjiang	2152N	11158E	23	195209-200712
57957	Guilin	2519N	11018E	164	195101-200712
59023	Hechi	2442N	10802E	260	195501-200712
59211	Baise	2354N	10636E	173	195101-200712
59254	Guiping	2324N	11005E	42	195301-200712
59265	Wuzhou	2329N	11118E	114	195101-200712
59417	Longzhou	2220N	10651E	128	195301-200712
59431	Nanning	2238N	10813E	121	195101-200712
59632	Qinzhou	2157N	10837E	4	195210-200712

Although these data contain a relatively high temporal resolution, their low spatial resolution made it difficult to create an accurate map of growing degree days. In order to create a regional map that allowed us to examine trends across space, it was necessary to predict values in areas where we had no weather station data. In order to estimate the value of cumulative growing degree days in the areas lying between stations, an interpolation of these values was carried out in ArcGIS. To do so, I used a statistical tool known as co-kriging in ArcGIS v. 10.1. Kriging is a group of geostatistical techniques that interpolate the value of a field (i.e, elevation, growing

degree days) at a non-observed location from observations of its values at nearby locations. As such, it provides a means of interpolating values for points not physically sampled using knowledge about the underlying spatial relationships in a dataset to do so (ESRI 2011).

Co-kriging is an interpolation technique that allows one to estimate map values by kriging if the distribution of a secondary variable sampled more intensely than the primary variable is known (Cressie 1993). If the primary variable is difficult or expensive to measure, then co-kriging can greatly improve interpolation estimates without having to more intensely sample the primary variable (Ripley 2004). Co-kriging can use information from two or more variable types. It is essential that both the primary and the secondary variable are closely correlated. In order to perform a co-kriging, I needed to incorporate other variables that could be used to explain the temperature gradients across southwest China. For example, altitude greatly influences temperature ranges and in general a 100m rise in elevation accounts for a 0.6 degree Celsius drop in temperature (Yoshida 1981).

Prior to co-kriging, it is recommended that one perform a semi-variance analysis for the primary variant (in this case GDD), and for the covariate (altitude) to establish the existence of a relationship between the two variables (Cressie 1993; ESRI 2011). The semi-variogram and covariance functions in ArcGIS 10.1 quantify the assumption that things nearby tend to be more similar than things that are farther apart. Semi-variogram and covariance both measure the strength of statistical correlation as a function of distance (Cressie 1993). The process of modeling semi-variograms and covariance functions fits a semi-variogram or covariance curve to empirical data and allows the researcher to achieve the best fit. Once created this semi-variogram model can be used in predictions.

The empirical semi-variogram and covariance provide information on the spatial autocorrelation of datasets. However, they do not provide information for all possible directions and distances. For this reason, and to ensure that kriging predictions have positive kriging variances, it is necessary to fit a model (a continuous function or curve) to the semi-variogram and covariance. The geo-statistical analyst tool in ArcGIS has a number of models that can be fitted to the data (ESRI 2011). It is recommended to choose a model that passes as closely as possible to the averaged and binned values. The most common models are the Spherical, Gaussian and Exponential models. An examination of the semivariogram on a co-kriging between altitude and GDD revealed that a Circular model fit the data best, as this model passed closely to averaged and binned values.

The GDD data derived from the weather stations described above were used as a primarily variable and a Digital Elevation Model of the region derived from the China Historical GIS website was used as a secondary variable[2]. Because of its high temporal resolution, these data were also retained in order to calculate the risk involved with growing crops.

As different crops have different base temperatures below which crop growth is arrested, we processed daily weather data into growing degree days using a variety of different base

[2] Although we were not able to analyze these data for the purposes of this dissertation, we were also able to acquire high resolution satellite data from the Global Modeling and Assimilation Office (GMAO) at NASA Goddard Space Flight Center. We specifically were able to acquire the Goddard Earth Observing System Model: Version 5 (GEOS 5) dataset, which contained data from 2004-present and was collected on a 0.5° x 0.667° or roughly 50km grid. Temperature data for the GEOS 5 model were acquired from a number of different satellite sources, air balloon and other sources Rienecker et a. (2008) . Although the temporal resolution of this dataset was not comparable to the China Meteorological Administration Dataset, its high spatial resolution will allow one to create a high resolution map of total available accumulated growing degree days for the whole of China. Ultimately, I am in the process of starting a formal collaboration with the China Meterological Service that will allow me to have full access to high resolution weather reporting. Having access to this data will eliminate the problems I encountered with spatial resolution while writing this dissertation.

temperatures (0 °C, 5.5 °C and 10 °C). For crops aside from rice, we set the upper threshold at 30°C. For rice this threshold was set at 35 °C. These values were calculated on a yearly basis, except when dealing with winter varieties of wheat and barley, for which a start and end date for accumulative growing degree days was set as starting in September and ending in June of the following year. An accumulated GDD was calculated for each year present in the dataset. Data on accumulated GDD's were then averaged over the total number of years for which data were available in order to get an average GDD value for a given location. Co-kriging was carried out on these values which were then added to ArcGIS as layer files. All weather data manipulation was carried out in Microsoft Excel and formulas to manipulate this data were designed with Harvard undergraduate in Earth and Planetary Science, Jane Baldwin. The maps produced from co-kriging these data were then color coded according to the number of growing degree days required for each crop. As a result, different maps were created for each species of interest. In this analysis, I have used modern weather data as a proxy for conditions in the past. As an analysis of growing degree days requires daily min and max data, it was not possible to carry out such an analysis for past climate conditions without some understanding of how fluctuations in ancient climate altered daily surface temperatures. Further modeling is needed in order to address how species distribution models can be created for past weather conditions.

3.2) Analysis of Risk

Finally, I used ArcGIS to model the risk associated with practicing a given crop. While an area may contain enough average GDD's for a crop to be grown, it is important to understand how risky an endeavor growing such a crop might have been (i.e, out of x number of years, how many

years would this crop have failed). In order to calculate this statistics, I divided the number of years where a crop would fail during which there were not sufficient numbers of growing degree days to allow the crop to achieve maturity (given current weather data), by the number of total years in dataset for each weather station. Risk was thus expressed as a percentage of failure. Maps of risk were created by co-kriging risk as a primary variable against altitude using the methodology described above.

3.3) Acquiring data to test the model: Methods for Archaeobotanical Analysis

Samples for archaeobotanical analysis were collected from a variety of different sites and contexts spanning the earliest occupation of the Chengdu Plain (2700 BC) to the Han Dynasty (206 BC-220 AD). Archaeobotanical data were extracted from these sites in order to provide data to determine if the patterns predicted by ecological niche modeling held true.

3.3.1) Samples from sites under excavation

Samples analyzed for this dissertation were derived from excavations carried out by the Chengdu City Institute of Archaeology, the Sichuan Provincial Institute of Archaeology and Sichuan University. Samples were derived from 17 different sites situated in the Chengdu Plain and three sites on the Tibetan Plateau. Excavators were instructed to take samples of between 15-30 L from all archaeological contexts of interest. This included samples from ashpits, house floors, post-holes, graves, ditches and other contexts, such as hearths, which show evidence of burning. Control samples were also taken from stratigraphic layers and the surrounding matrix. Because

they contained large amounts of charcoal visible to the naked eye, samples from ashpits were preferentially taken by the excavators and are overrepresented.

An exception to this sampling strategy occurred during the excavations carried out at the site of Changdu Karuo on the Tibetan Plateau. Smaller samples (between 1-2L) were taken at these sites because they were excavated in 2001, before a methodology for sampling for archaeobotanical remains was properly implemented in this region. In addition, I also examined data from samples that had already been published, including Yingpanshan (Zhao and Chen 2011) and Changguogou (Fu 2000;2001), sites from the Chengdu plain analyzed by Shi Tao at Peking University (Shi 2012), and data from Haimenkou examined by Xue Yining at Peking University (Xue 2010).

3.3.2) Samples from Survey Archaeobotany

A small number of additional samples were derived from contexts identified during the Chengdu Plain Archaeological Survey (CPAS). Growing interest in documenting regional variation has led to increasing attempts to extract archaeobotanical remains from archaeological surveys. The earliest example of a survey that explicitly incorporated the collection of archaeobotanical remains is that of the Deh Luran Plain survey in Iran (Helbaek 1969). More recently, survey archaeobotany has been employed as a means to retrieve data from sites that are either unexcavated or that were not sampled for archaeobotanical remains in previous seasons of excavation. This approach has become increasingly popular in East and Southeast Asia where it has been instrumental in documenting the introduction of domesticates

and changes in agricultural regimes. Examples include Fuller's work in the Kunderu River Basin (Fuller, et al. 2001) and central China (Fuller and Zhang 2007; Zhang, et al. 2010), Lee's (2007) work in the Yiluo River Basin, and Barton's (2003) work in northwest China.

Sampling for archaeobotanical remains in sites not under excavation is challenging, and a number of different methods can be used to approach these sites. Simple strategies include returning to visible trenches of old excavations (Barton 2003; Fuller 2000) or taking opportunistic samples from agricultural terrace cuts. Taking samples from terrace cuts has proven particularly useful on the loess plains of northern China, where features are often visible in terraces (Barton 2003; Flad, Li, et al. 2010; Lee, et al. 2007). Digging small-scale test pits is another solution that has been used for extracting archaeobotanical data (Barton 2003; Harvey, et al. 2006; Helbaek 1969).

Although many sites were located during the CPAS survey, these sites were buried under the alluvium, making sampling through terrace cuts impossible in this region. We thus decided to use test pits to locate archaeobotanical remains. Deciding where to place a test pit can be challenging in environments where stratigraphic cuts through sites are rare or site features are otherwise invisible on the surface and we experimented with two different solutions for identifying concentrations of carbonized remains.

Trials with Bucket Auger: We began by using bucket augers to try pinpoint the location high concentrations of charred remains. A preliminary trial was carried out at the site of Shiweigan, which had been previously identified through pedestrian and auger survey during the summer of

2009. During this trial, we tried to pinpoint areas of high charcoal density using bucket augers. A series of 20 auger points were carried out at regular intervals across the surface of a previously identified site in order to pinpoint the location of charcoal rich deposits. Two areas with some charcoal and the densest pottery concentration were selected for the placement of two 1x1m excavation units. We were unable to replicate these finds in the two excavation units. Although faint cultural layers were uncovered in these two test pits, no features were visible and we failed to find large amounts of charcoal. Samples for flotation were taken from layers in these pits, however did not yield any carbonized seeds. Augering to determine the location of a pit was labor intensive and time consuming, we thus decided that augering was not an efficient strategy for determining the location of test pits.

Trials with Magnetometry

Following this first trial, we worked together with the CPAS project magnetometrist, Dr. Timothy Horsley to develop a new method of pinpointing the location of features likely to contain high quantities of charcoal. Magnetometry relies on a magnetic contrast between archaeological features and the surrounding natural sediments, and when successful, magnetometry can detect the slightly elevated magnetic fills of buried pits and ditches, and features such as hearths where the soils and clays have been burnt, thereby enhancing their magnetization (Chengdu Pingyuan Guoji Kaogu Diaochadui 2010). While magnetometry cannot detect high densities of charcoal itself, it can be useful in finding features such as *huikeng* (pits for trash or storage) where large quantities of discarded ceramics, plant remains, faunal material and other domesticate refuse were sometimes burnt causing their magnetic enhancement.

A number of sites were mapped using a magnetometric survey during the CPAS project and used these maps to select appropriate loci for sampling. Dr. Horsley's maps were used to target a number of features including ashpits, house foundations and ancient canals. A total of four different sites were selected to carry out these trials. Because of the constraints of our survey permit, we were only allowed to carry out 1x1m excavation units.

1.) *Shiweigan*: To begin these trials we returned to the site of Shiweigan during the winter of 2009. During this season we targeted two anomalies that were thought to be ash pits using the precise locations of these features on the maps. One identifiable pit was found in Unit 1 and soil samples were taken from this feature (Figure 3.2). This feature contained large amounts of burnt earth, and small amounts of pottery fragments relating to the Baodun period as well as a ground stone tool. Despite the presence of these features, only small amounts of charcoal were recovered. In a second excavation unit (Unit 2) a weakly expressed pit was also found from which a soil sample was taken (Figure 3.3).

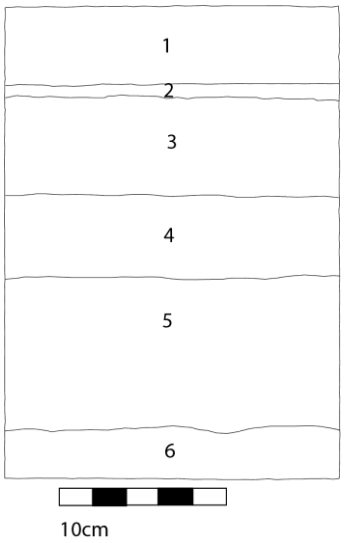

Figure 3.2 Unit 1 Shiweigan

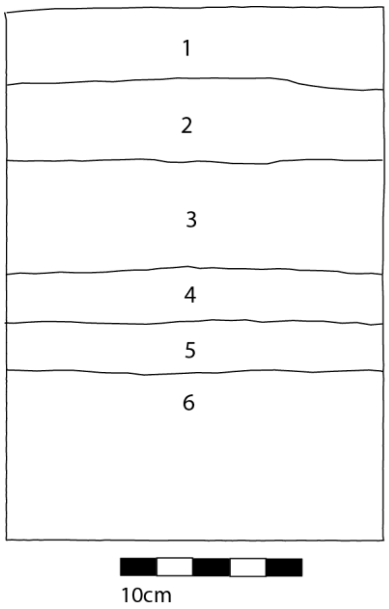

Figure 3.3 Unit 2 Shiweigan

2.) *Songjiaheba*: The site of Songjiaheba was identified during the winter of 2006 by the CPAS survey and was selected for investigation, as the site was under threat from sand mining activities. Small-scale excavations were carried out at the site during April 2007. At the time, however, no samples for archaeobotanical analysis were collected from the site (Flad, et al. In Preparation). Radiocarbon dates on charcoal from these excavations place its dates between 1510-1370 Cal BC and 1260-1010 Cal BC: the transitional period between Jinsha and Sanxingdui. The dates of this site made Songjiaheba a priority of investigation, as at the time no archaeobotanical evidence had ever been extracted from a Sanxingdui period site.

During the summer of 2009, two test pits were carried out at Songjiaheba using maps created by Dr. Horsley. We targeted two anomalies consistent with ash pits based on the magnetometry

readings. Ashpits were found in both of these excavation units and exceptionally large amounts of pottery and charcoal were unearthed. The pottery unearthed from these features was consistent with previous finds at the site and dated roughly to the late Sanxingdui period. The first small 1 x 1 m excavation unit, Unit 1, was placed at the location of a large magnetic anomaly. This unit was excavated to sterile soil at 60 cm. Three stratigraphic layers were visible in this unit. Directly underneath the topsoil, an artifact and ash-rich layer was unearthed. Although the boundaries of this feature were not found within this 1 x 1 m unit, the large quantities of charcoal, pottery, and ground stone tools contained in the matrix were consistent with the fill of an ash pit (Figure 3.4). A large sediment sample (53L) was taken from this layer.

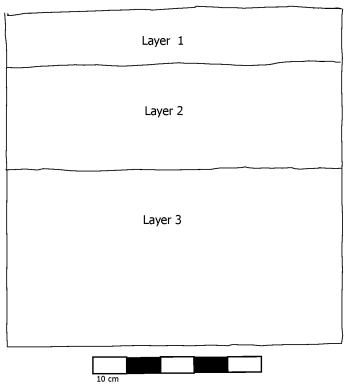

Figure 3.4 Profile of Unit 1 at Songjiaheba

Unit 2, a second small unit placed over another anomaly, had more complex stratigraphy and, like other areas of the site, contained 5 stratigraphic layers. Underneath topsoil, the second stratigraphic layer contained “Shang / Zhou” period (ca. 1500-300 BC) pottery and some ashy inclusions. An 11 L soil sample was taken from this layer. A thin stratum (Layer 3) containing

no pottery or ashy inclusions was not sampled. Layer 4 contained a few ashy inclusions and an additional 13L soil sample was collected. Situated underneath this layer and cutting into what appeared to be sterile soil were the clear boundaries of an ashpit (Figure 3.5). An additional large sample of 31 L was taken from this feature (Figure 3.6).

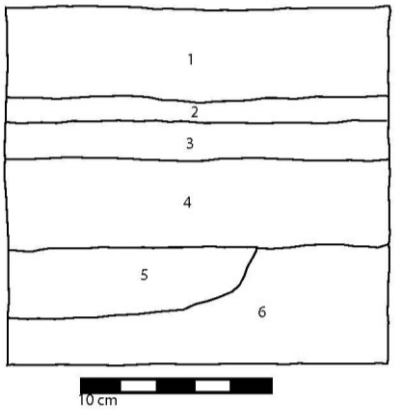

Figure 3.5 Profile of Excavation Unit no. 2

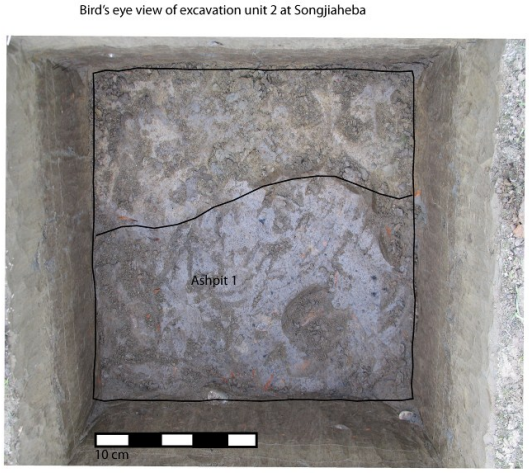

Figure 3.6. Bird's eye view of Excavation Unit no.2

Zhongpingcun: The site of Zhongpingcun was also targeted, as large amounts of Baodun ceramics had been unearthed at this location during the auger survey. Our attempt to sample at this site took place during December of 2009. Winter crops such as cabbage and other vegetables filled the surface of the site and we were not able to target features such as ashpits. We therefore decided to test the efficacy of sampling from different kinds of features and chose an ancient canal and what appeared to be house foundations as the location for our two test pits. A canal (Unit 2) that was dated to the Han dynasty based on pottery chronology was found in the first feature, however no charcoal was recovered from the soil samples taken in this feature (Figure 3.7). Below this canal, a soil sample was taken from a weakly expressed Baodun cultural layer that yielded only 2 carbonized seeds.

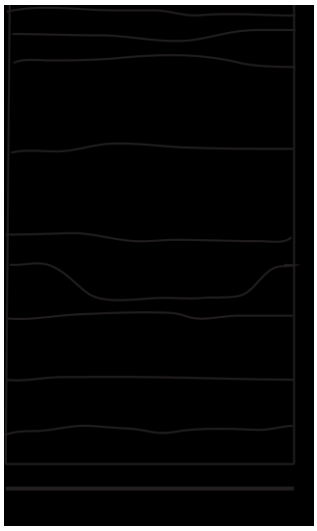

Figure 3.7 Zhongpingcun Unit 2

In a second unit (Unit 1), we targeted a feature that was associated with house foundations (Figure 3.8). No clear features were unearthed in this unit, although a light scatter of burnt earth and highly fragmentary pottery was present. It is possible that this feature may have been some

kind of living surface but very little charcoal was found and the soil extracted from this feature yielded a total of only 6 seed fragments.

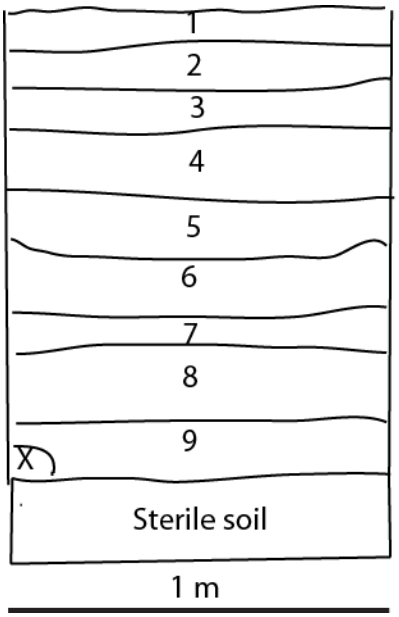

Figure 3.8 Profile of the north wall of Unit 1 of Zhongpingcun. X marks an area where pottery was found.

Qingmingcun: We carried out additional excavations at the site of Qingmingcun during the winter of 2009. Two 1x1m excavation units were placed over a highly magnetic feature visible on the magnetometry readings at this site. Excavations discovered a round agglomeration of burnt pebbles covered in large quantities of charcoal and burnt earth (Figure 3.9). The exact nature of this feature is still unclear, however pottery chronology indicates that this feature dated to the Han dynasty. A high volume of charcoal was retrieved from this sample, however, no

seeds were unearthed, suggesting that it is likely the remains of a fire associated with abandonment or intentional burning.

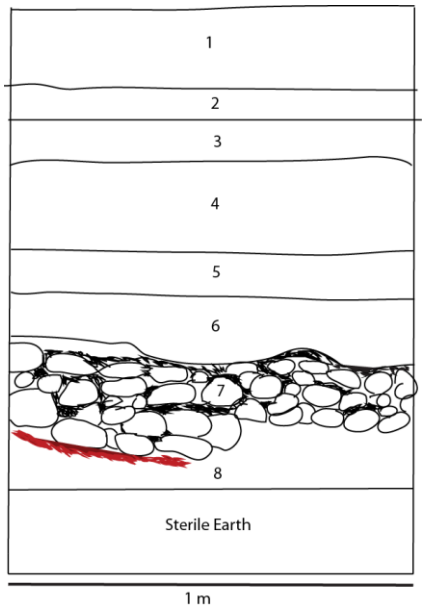

Figure 3.9 Unit 1 at Qingmingcun. A Han dynasty destruction layer with large amounts of pottery and stone and charcoal was uncovered. Baodun period ceramics were found unearth this destruction

The very low numbers of seeds extracted from these excavations meant that this was not an effective strategy for extracting sufficient archaeobotanical material from across the Chengdu plain.

3.3.3) Sample size

The size of soil samples used in this dissertation varied between sites and between excavators. While consistency in sample size is good, it is not necessary, and density ratios can be used to calibrate for differences in the amount of soil (Pearsall 2000). The number of liters of sediment required to produce a statistically significant number of seeds is highly variable according to sediment and feature conditions. If a particular feature contains large quantities of non-organic material (e.g., burnt clay from mud brick houses) then sample size should be increased. The nature of the matrix should also be taken into consideration. In particular, sediment with high clay content are deleterious to the preservation of charred remains, as charred plant remains are soaked in water on a year round basis (Wright 1998, 2005, In Prep). Larger samples should be taken from these samples in order to account for preservation bias. Except for the sandy river swathes described above, soils in the Chengdu Plain are high in clay content, and this had an effect on the preservation of carbonized remains. On average, we recovered only 27 seeds per liter, much lower than the values reported for other regions of China. In areas with sandier, more silty sediment that is lower in moisture content, such as northern China, much higher concentrations of archaeobotanical remains are unearthed on average (Lee, et al. 2007; Zhao 2004, 2005, 2010a). For the United States, Pearsall (2000) recommends starting with 10L samples[3] and evaluating the quantity of material recovered. In the Chengdu Plain we found that, except for uncharred remains preserved underneath silty swathes, samples of 25L or larger were needed to yield satisfactory quantities of seeds.

3.3.4) Sampling for Starch and Phytolith Analysis

[3] In the Americas, 10L samples have tended to be the standard, while in Eurasia sample size has been more variable.

Roughly 300g of sediment were set aside from each sample for phytolith and starch grain analysis. Phytolith and starch grain analyses of the samples were carried out by PhD student Chen Tao at the Chinese Academy of Science. Phytoliths represent parts of plants, and by carrying out phytolith analysis it is possible to determine if certain plant plants (not represented in the macrobotanical record) were carried to the site. Phytoliths can thus be useful indicators of anthropogenic activity such as crop processing, and in some cases the type of agriculture practiced (Harvey and Fuller 2005; Piperno 2006b; Rosen and Weiner 1994). Starch grains can represent economic parts of plants that are perishable and rarely preserved, such as tubers (Torrence and Barton 2006). By combining these three approaches, a more comprehensive picture of ancient plant use at a given site can be formed.

In addition to samples of starch and phytoliths from sediments, samples for phytolith and starch grain analyses were collected from dental calculus, pottery and stone tools. Starch and phytoliths embedded in dental calculus can provide important information about individuals' meals (Hardy, et al. 2009; Henry and Piperno 2008; Juan-Tresserras, et al. 1997; Lalueza Fox, et al. 1996). A total of 33 samples of dental calculus from individuals ranging from the Baodun to the Shi'erqiao period were extracted. Samples were also taken from 95 different pieces of stone tool and pottery residue. Once analyzed, these samples will complement the results of the macrobotanical analysis.

3.3.5) Pre-flotation Curation of Samples

Where possible, samples were air dried in the shade on a plastic tarp in a large bamboo basket before being placed in bags for storage. All samples were placed in breathable plastic bags for storage in the Chengdu City Institutes' warehouse at Beihu. Each sample contained two different identifying tags. One was placed on the inside of the bag and the other was placed on the outside.

Prior to flotation, it was ensured that samples were dry. If samples were still moist they were placed on the tarps and allowed to dry in the shade for a few days before floating.
Because it is difficult to make sure that all samples have an equal volume of soil in the field, the number of liters in each dried sample was recorded using a graduated bucket in order to allow density measures to be calculated. Samples of different sizes can be compared using density measures. Weight was also recorded using an electronic scale. Each sample was given a flotation number and all information relating to the sample was entered into a Microsoft Excel spreadsheet. Plastic tags were created and attached to each sample.

3.3.6) Flotation methods

All samples, except those from the site of Guiyuanqiao, were floated at the Chengdu City Institute's warehouse at Beihu. Samples from Guiyuanqiao were floated at the Sichuan Provincial Institutes' Research Base at Sanxingdui. All flotation was carried out at my direction or that of my collaborator in the field: Jiang Ming. Although I was present at all times, Zhang Qian (MA student, Sichuan University) and Fu Chang (PhD student, Arizona State University) and Birgit Guedes also assisted with large portions of the flotation. For 10 days during the summer of 2010, students from Sichuan University were trained to carry out flotation and assisted in floating a portion of these samples.

A wide variety of different flotation techniques exist. Machine assisted flotation machines use pump or tap pressure to wash soil. A sample is placed onto a mesh that captures the heavy fraction. The tank is filled with water and water sprays the sample from underneath, causing light carbonized material to rise to the surface (Pearsall 2000). Some machines such as the commercially produced Flote-Tech system use air pressure to froth samples (White and Shelton In Prep). Machine flotation has been popularized in East Asia by Gary Crawford and Zhijun Zhao. In the late 1980s, Crawford created a hybrid froth flotation/SMAP tank that was transportable and that accommodated the processing of large samples (Crawford 2011). In recent years he and his team have developed a hybrid SMAP tank that is smaller in size and now widely used throughout Japan and China (Lee et al. 2007; Zhao 2007). Zhao (2007; 2010b:31-36) has popularized the use of this machine throughout China by donating machines to Archaeology Institutes.

In bucket flotation, a portion of the sample is poured into a bucket. Water is added to the sample and the sample is gently agitated using hands or a stick. Carbonized material rising to the surface is then poured into a set of graduated sieves or 0.25 mm cloth. Heavy fractions are processed by pouring the remaining sediment into a 1mm sieve and washing.
Bucket flotation has also recently become popular in China, thanks to the efforts of Dorian Fuller and Qin Ling. This technique is primarily used by the Peking University archaeobotany group.

The Chengdu City Institute of Archaeology owns one of Zhao Zhijun's SMAP machines, and it was placed at our disposition to float these samples. Prior to starting flotation we decided to

compare the efficiency of this machine with that of simple bucket flotation. To do so, we selected samples of minor importance and divided each sample into two halves. One of these halves was processed using the SMAP machine and one half was processed using simple bucket flotation. As we began our flotation machine, it became immediately apparent that soils in the Chengdu Plain were high in clay content and difficult to float. The lack of manual agitation in the SMAP machine made clods of earth difficult to break up. In addition, we noted that although many carbonized plant remains were present in the samples, it was difficult to make specimens float to the surface because they remained embedded in the clay matrix for a long enough period of time to become water logged and these ended up in the heavy fraction. Loss occurred as these fell through the mesh of the heavy fraction. Bucket flotation, on the other hand, afforded much greater control over the sample. Using bucket flotation we were able to avoid loss, as seeds that were difficult to float stayed in the bottom of the bucket. In addition, we were able to adjust the number of times we poured each sample to the amount of visible carbonized remains at the bottom of the bucket. It further became apparent that bucket flotation was a preferential solution when it came to cleaning the SMAP tank. Cleaning the SMAP tank and heavy fraction mesh was time consuming and labor intensive compared to cleaning the buckets and sieves used in bucket flotation.

As the warehouse at Beihu had its own well and pump we were not limited by the use of water in our choice of selecting a flotation method. The samples were thus floated using bucket flotation, as described in Fritz (2005:780-784), Pearsall (2000:29-33), and Watson (1976:79-80) as this allowed a higher degree of control and reduced breakage and fragmentation (Figure 3.10). Samples were first air dried in the shade to remove excess moisture and once dry, small quantities of soil were gently agitated in water to release carbonized organic material. After

agitation, organic materials were decanted from the upper portion of water. A nylon mesh of 0.25-mm was used to catch light fraction material. Samples were hung to dry in a cool, dry area. Heavy fraction material was caught on a 1-mm geological sieve.

Figure 3.10 Carrying out bucket flotation at the Chengdu City Insitute of Archaeology's warehouse at Beihu

Because of the large numbers of uncarbonized material, geomorphological samples would have clogged the mesh used in bucket or SMAP machine flotation. For this reason, these samples were processed using the water sieving technique (White and Shelton In Prep). Samples were placed in a bucket in the same way as bucket flotation and after a few agitations the entire sample was poured into a set of graduated sieves of 2-mm, 1-mm, 0.5-mm and 0.25-mm and then

gently washed with a stream of water to remove excess sediment. Each fraction was separated and then hung to dry in the 0.25-mm nylon mesh.

3.3.7) Packaging and storage

Once dry, samples were brought to the laboratory at Sichuan University, where they were divided into 2-mm, 1-mm, 0.5-mm, 0.25-mm and <0.25-mm fractions using a standard mesh geological sieve. Each of these fractions was placed in a separate plastic bag that was labeled using a Sharpie. These were stored in plastic boxes to prevent further mechanical damage to the samples. Samples were sieved by myself, and on several occasions I was assisted by students from Sichuan University, Harvard University undergraduate students (Matthews Mmopi, Manuel Rincon Cruz, Steve Teng and Florence On), and Harvard Korea Center Post-Doc Martin Bale.

3.3.8) Laboratory Methods

Samples were analyzed at the laboratory at Sichuan University and at Harvard University.To ensure efficiency and maximum data collection, different methods were applied to the sorting of fractions. The 2-mm fraction was sorted in its entirety into seeds, charcoal, other plant parts, other charred material, modern seeds and residue (dirt, rocks, rootlets, leaves, modern insects, etc.). Bone and shell were removed from all fractions and put aside for future analysis.
Seeds and plant parts were then identified; charcoal was reserved for subsequent analysis. The 1-mm and 0.5-mm fractions were sorted in their entirety for both carbonized and modern seeds, however charcoal and other fragmentary plant parts were not pulled from these fractions. Because of the large amount of inorganic residue such as sand in the 0.25-mm fraction, these fractions were not sorted in their entirety. An average of ¼ of the total 0.25-mm fraction was

sorted. Identifiable plant parts such as rice spikelets bases, were pulled from all fractions. Heavy fractions were briefly scanned in the field to retrieve carbonized material, however these were not sorted in their entirety for ceramic, stone tools and bones. All heavy fractions are currently stored at the Beihu warehouse and are available for further analysis. Plastic centrifuge tubes were used for storing seeds and other material pulled from the samples. We did not use gel-caps, as a radiocarbon specialist confirmed that these may interfere with dating samples (Wu Xiaohong: Personal Communication 2012).

3.3.9) Reference collection

Identification of seeds from the Chengdu Plain was carried out on the basis of morphology and by making reference to three different sources. 1.)Reference Collections: A personal reference collection created by collecting plants in the field and requesting samples from the USDA and Harvard Universtiy Herbarium. Specimens that could not be removed from the Harvard University Herbarium were consulted and documented in the collections, often forming the object of a loan in order to photograph. In addition, I also accessed the collections at Univeristy College London (UCL). These were accessed on two different occasions to check identifications with the help of professor Dorian Fuller. On one occasion, I used the reference collection material of Professor Zhao Zhijun at the Chinese Academy of Social Sciences. 2.) Illustrated archaeobotanical and modern seed identification guides from the region and Asia as a whole were extensively consulted (Cappers, et al. 2010; Cappers, et al. 2006; Davis 1993; Flood and Gates 1986; Fuller 2006; Fuller 2002; Jacomet 2006; Li 1998; Liu, et al. 2008; Moody 1989; Musil 1963; Nakayama, et al. 1996; Nesbitt 2006; Raju 1999; Soerjani, et al. 1987). The *Flora of China* (Wu, et al. 2006) was frequently used to determine the list of species present in the

Chengdu Plain and to narrow down identifications. 3.) Help with unidentified specimens was sought using the archaeobotany listserv at www.paleobot.org, a website created by myself and Christina Warinner to assist with the identification of archaeobotanical remains (Warinner, et al. 2011).

Most seeds can be identified to genus, with some taxa identifiable to species, such as domesticates (e.g., *Setaria italica*). In many cases archaeological types fail to match a modern type precisely; these uncertain identifications are marked with a "cf." (compares favorably) before the genus or species, depending on the level of certainty.

Samples were sorted by myself. Help with sorting samples was given by Zhang Qian (a master's student in archaeobotany at Sichuan University), who I trained and is able to make identifications of common domesticates. Additional samples were sorted by Martin Bale, a postdoctoral fellow at the Korea Center of Harvard University. Martin Bale received previous training in archaeobotany at the University of Toronto where he studied under Gary Crawford. Volunteers pulled plant fragments from samples and identified specimens that were known to them through training. All fractions of samples sorted by volunteers were checked by myself in their entirety to ensure that all plant parts were removed. All final identifications and data entry were done by myself.

Images of all reference collection materials and identified seeds are placed in the appendix and online at www.paleobot.org.

3.4) Statistical analysis in archaeobotany

In order to interpret the archaeobotanical remains from Southwest China, we carried out several different kinds of statistical analysis. As Marston (In Review) has pointed out, simple statistical measures can be divided into three different categories. 1.) Descriptive methods of quantification are based on solely the number of seeds or plant parts (These include absolute counts, rankings and food value estimates), 2.) Standardized methods are those that peg the absolute count to the category of remains to which a taxon belong to another standardizing variable such as the liters of sediment floated (these include density, proportions, ubiquity and Z-scores). Finally, 3.) Relative methods compare the absolute count value of a taxon to the value of another (these include comparative ratios as well as indices of diversity).

I use a number of standardized measures to interpret the data from Southwest China. As the number of liters sampled from different contexts can vary widely, different sample sizes can provide highly different seed counts. Standardized measures can be used to avoid this problem and to increase comparability. The first standardized measure I employ in my analysis is *seed density*. This is calculated by dividing the total number of seeds present in a sample by the volume of soil floated (Marston In Review; Pearsall 2000:196-199). An analysis of density for all samples examined in this dissertation revealed that the number of liters sampled did not have a huge effect on seed counts (Figure 3.11).

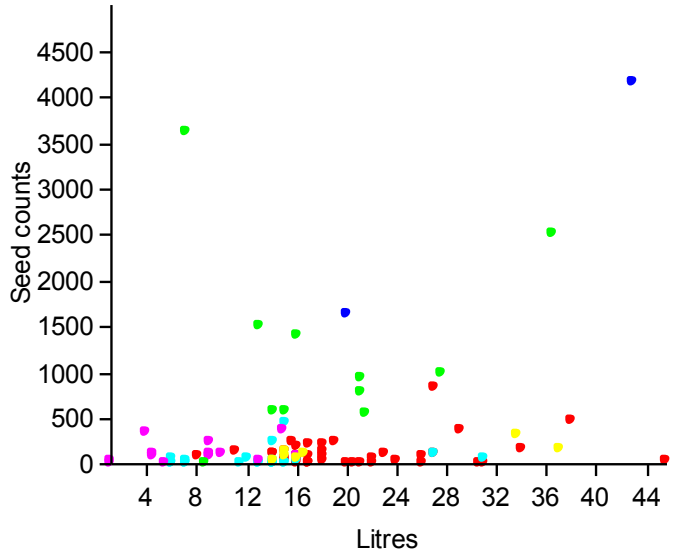

Figure 3.11 Density of total seed counts by site (Red= Baodun; dark blue=Zhonghai; turquoise=Guiyuanqiao; pink= Qingyang; Green=Bolocun; Yellow=Sanhehuayuan)

Density measures are also carried out for domesticates on a taxa by taxa basis.

The second type of standardized measure I employ is based on ratios with unlike numerators and denominators. The first of these is the *total seed to charcoal ratio*, which allows me to gain an understanding of the formation processes that lead to the creation of different samples. This can help distinguish samples created from burning wood (i.e, hearths) from contexts like trash middens (Pearsall 2000:203).

As dung burning has not been attested in this area of China, and it is understood that pastoral lifestyles only began much later, I do not use measures destined to identify dung burning, such as the wild seed to cereal ratio or the wild seed to charcoal ratio (Marston 2010; Miller 1984, 1990, 1996; Miller and Smart 1984). As all of these ratios are density-independent measures and are standardized against a common component of flotation samples, they do not need to be further

adjusted to account for differences in soil volume and can be readily compared between archaeological sites.

Another quantitative measure that is commonly used is *ubiquity*. This kind of analysis can be useful for determining which plants frequently find their way into archaeobotanical assemblages. Ubiquity is essentially a presence/absence measure and calculates the frequency of a particular taxon (or group of taxa) across a number of samples (Marston 2010; Pearsall 2000: 212-216; Popper 1988:60-64). While commonly used, ubiquity is a problematic measure and its value has been widely debated (Kadane 1988; Pearsall 2000:214). Several problems arise with this measure. VanDerwarker (2010) gives the following example. A 70% ubiquity for hickory nutshell that represents a processing by-product is not comparable to a 70% ubiquity value for beans that represent edible plant parts. In comparing the two, Kadane (1988:209) points out that hickory nutshell also has a better preservation likelihood than that of beans. In addition, hickory nutshell is a plant part that cannot be consumed, whereas beans are consumed by humans as a primary food source and as a result, one would only expect these to end up in an archaeological deposit when they have accidentally been dropped or discarded, have spoiled or where storage structures are accidentally burned. In addition, Kadane points out that ubiquity depends largely on preservation and volume. As a result, scholars (Hubbard 1976a; Kadane 1988; Popper 1988) have recommended than an analysis of ubiquity should only be carried out on samples come from similar contexts and sampling measures.

As a result, I suggest that one should only calculate ubiquity from samples whose volumes are comparable, and that otherwise show comparable preservation patterns. As Pearsall (2000:214)

points out, ubiquity can be misleading if samples are variable as it can obscure intrasite variation. In addition, Hubbard (1976b:160) suggests that a minimum of ten samples is required to reduce the probability of sampling error. As Popper and Hubbard point out, other problems can occur with ubiquity. Samples used for an analysis of ubiquity must be independent (Hubbard 1980). Care must be taken, for instance, with destruction levels and one must be careful not to divide a sample that relates to a single event into many (Hubbard 1980). For instance, if one sample is treated as two independent samples this will automatically inflate the ubiquity count.

An example is provided in Hubbard's re-analysis of the data from Çayönü (summarized by Popper 1988). An initial analysis of the data grouped samples on a chronological basis and claimed to see a shift from cereals to pulses. However, when the data were re-analyzed and grouped samples by location at the site, different patterns emerged. A chronological analysis assumed that each group represented the full range of plant use at Çayönü during the time period, when in fact it did not and in fact differences in activities at different localities of the site better accounted for this patterning.

Hubbard (1976a, 1980) has also used ubiquity with very large datasets from Europe to explain the spread of 11 different crops into Europe. The large size of this dataset allows him to reduce the amount of error associated with small sample sizes. To this end, I have first carried out an analysis of seed density and only used samples from contexts that share similar densities. Samples that have too low of a seed density are likely to be biased and hence have been eliminated from an analysis of ubiquity. In addition for my analysis of ubiquity only certain

contexts have been selected for analysis. The majority of samples analyzed for this dissertation come from two particular kinds of context: ashpits and stratigraphic layers.

In addition to ubiquity, I also utilize a number of relative measures. In order to assess the importance of different taxa at the site, I use a number of comparison ratios, where the numerator and denominator represent different taxa or categories of taxa. In recent years, comparison ratios have been used to identify a wide variety of patterns across archaeological sites. For instance, Marston has examined the proportions of seed taxa to document environmental disturbance and degradation at the site of Gordion in Turkey by using a ratio of plants that represent either healthy or overgrazed steppe (Marston 2010; Marston 2011, In Review). Miller has used ratios of seed counts to wood charcoal to document dung burning in pastoral communities (1984, 1996, 1997), and others have used ratios of weed seeds to grain, grain to chaff and the proportion of large to small weed seeds to document changes in crop processing (Fuller and Stevens 2009; Stevens 2003b).

For each crop, I look at the ratio of the crop's seed count to the total cereal count. In addition, I examine the ratios of different crop counts to each other. For example, I analyze the proportion of rice to millet and the proportions of rice to other cereals. I first carry out an analysis of the total number of weed seeds to other taxa. I also use these relative measures to understand the patterns underlying different weed flora and examine the proportion of weeds associated with paddy and dryland environments as a proportion of the total wild seed assemblage.

Summary

Ecological niche modeling can be used to determine the potential niche of crops grown in prehistory. This chapter describes the methodology used to create a mechanistic model for understand the potential niche that could be occupied by the five main domesticates grown throughout this region in prehistory. After gathering data from contemporary weather stations in order to give an idea of the variation in temperatures required for crop growth across this region, I describe the methods used to map the thermal niche of these crops using growing degree days. Because I was only able to acquire weather data from a small number of stations, I use a statistical interpolation technique (co-kriging) to improve the accuracy of these maps. I also discuss how contemporary weather data were used to estimate the risk associated with practicing different types of agriculture in Southwest China. This chapter also describes the data used to test the predictions created by these species distribution models. I describe the methods used to collect archaeobotanical data and the trials carried out in the field to extract archaeobotanical data from surface surveys. Finally, I discuss the statistical techniques used to analyze these remains. The next chapter outlines the biogeographic context within which this research is carried out.

CHAPTER FOUR

THE BIOGEOGRAPHY OF SOUTHWEST CHINA

4.1 The Geology and geography of Southwest China

The region of Southwest China covers the municipality of Chongqing and the provinces of Sichuan, Yunnan, and Guizhou in the People's Republic of China. The topography of Southwest China differs considerably from that of the rest of southern China. To the east, the areas surrounding low lying Middle and lower Yangzi River are composed of relatively large open expanses of land where the altitude rarely rises above 300 m. In prehistory, substantial portions of this area where covered in wetlands, such as the Jianghan plain. While eastern China is composed of a series of wide open plains, where the altitude rarely rises 100 meters above sea level, western China has a wide range of topographies. Both in Northern and Southern China, the western half of the People's Republic of China is characterized by a series of mountain ranges and by drastic changes in elevation compared with the low lying river valleys of the East. Southwest China is no exception to this rule and this region is comprised of several important physio-geographic zones. Yao (2010) has argued that unlike central China and Southeast Asia, the Yunnan Guizhou plateau lacks broad alluvial basins that both demarcate natural geographic regions and provide favorable conditions for reliable agriculture. Aside from the Sichuan Basin, she argues that only 4% of the landmass is considered arable and is concentrated in elevated lacustrine basins.

The Sichuan Basin forms the exception to this rule, and is the only very large low lying area in the whole of Western China. The Sichuan Basin was created as a by product of tectonic uplift of the Tibetan plateau (60 million years ago). This uplift created an inland sea that evaporated during the Middle Pliocene (ca. 3.4-1.6 Mya) leaving the Sichuan Basin separated from surrounding regions by mountain ranges on all sides (Li, et al. 2001). This basin can be divided into three main geographic zones: the Chengdu Plain in the northwest, the Central hills and Jialing river valley in the center and a series of valleys of vertical mountain chains in the East. The Chengdu Plain is the largest area of flat land in southern China and covers over 8000 square meters. The Chengdu Plain is covered in alluvium that is the result of 8 rivers deposing their gravel and sand onto this area (Sichuan Sheng Difang Zhibian Fuyuan Hui 1996).

The plain is surrounded by several mountain ranges. To the west, the basin is surrounded by the Hengduan mountain range that forms the first cordillera of mountains of the Qinghai Tibetan Plateau, here the altitude rapidly rises from 500 to 3000 masl. The north of the basin is surrounded by the Qinling mountain range that rises to 2000-3000 masl, separating the Sichuan lowlands from the Wei River valley. In the east, a southeastern extension of the Qinling range called the Daba Mountains divides Sichuan from the Han River valley of the Middle Yangzi region. The Wushan mountains and the Three Gorges (1000-3000 masl) flank the basin to the east, separating it from the low lying plains of the Middle Yangzi river valley (Flad and Chen 2013; Li, et al. 2001; Xiang, et al. 2007).

To the South and Southeast, the Yunnan-Guizhou plateau rises to heights of between 1000 masl in the south and east and 3700 masl in the Northwest, covering the provinces of Yunnan and

Guizhou. This area is criss-crossed by numerous mountain chains that create a wide variety of ecological habitats. These mountain chains run generally in a north-south orientation, perpendicular to the Tibetan plateau. In Western Yunnan Province, the southern continuation of the Hengduan mountain chain is a complex chain ranging in altitude from 1300-6000 meters. Aside from a few flat expanses of land surrounding large lakes like the Dianchi and Erhai, the majority of the Yunnan-Guizhou plateau is surrounded by high mountains traversed by deeply cut river valleys, creating a landscape that is highly orthographically defined. The foothills of the Yunnan Guizhou Plateau taper towards the south running into Northern Thailand, Laos, Myanmar and Vietnam, where they lower to an average height of 1000 masl. To the east, in Guizhou province these mountains reach an average height of 1200 masl, and karst processes have created ravines, sinkholes and small highly tapered mountains, leaving very little space with flat land. It is not surprising that in historic times, the lake valleys in the Yunnan-Guizhou plateau and the Sichuan Basin became the most densely populated regions in Southwest China (Lee 1982).

Southern China is affected by the East Asian monsoon. The East Asian monsoon creates a highly seasonal pattern of rainfall with over 60% of the annual precipitation occurring during the summer months of June, July and August. The monsoon leads to different patterns of rainfall across China. In general, years of weak summer monsoons lead to more rain in the south and drought can ensue in the north. During years of stronger monsoons the pattern changes and the south receives less rain than in years of stronger monsoon. However, rain patterns across southern China are not even. Southeastern China receives on average more precipitation than

southwestern China as much of this rain falls on areas of higher altitude such as the Three Gorges or is lost in the shadow of the foothills of the Himalayas (Ding and Chan 2005).

The unique topographic configuration of Southwest China has led to a range of different climatic conditions across it. The Sichuan Basin for instance has a warmer winter climate than surrounding areas and receives less precipitation (900-1300 mm) than in the mountains (1500-1800 mm) (Sichuan Sheng Difang Zhibian Fuyuan Hui 1996). In the Chengdu Plain, however, precipitation is higher than in other parts of the Sichuan Basin and generally ranges between 1000-1300 mm per year, with some areas close to the mountains receiving as much as 1700 mm (Sichuan Sheng Difang Zhibian Fuyuan Hui 1996) (Flad and Chen 2013). In Yunnan, annual average rainfall in the region exceeds 1,000 millimeters on southwestern slopes at higher altitudes, while areas of the northwestern part of the region, in the rain shadow of the Tibetan Plateau, rarely receive more than 400 millimeters annually (Chang 1983). The wide range of physiographic and local weather conditions have led to this region being the largest centers of biodiversity in the temperate world. Even though the array of species in this region is not yet fully documented, vascular plant diversity is estimated at about 12,000 species. Roughly 40% of all species known to China grow in this region (Yang, et al. 2004).

Highland eastern Tibet is characterized by warm, wet summers and dry, frosty winters. Average high temperatures of 20 °C are reached as early as May, although nighttime temperatures are much lower due to the effect of altitude, reaching only a monthly average of 5°C). In June, July and August, the average high is remains at a monthly average of roughly 23° C, with lows between 9 and 10 degrees (Chang 1981, 1983).

4.2) Current Vegetation Patterns

The latitude of southwest China places it in what should be a subtropical vegetation zone, however the geophysical configuration of this area has led to the presence of a range of different ecosystems from permanent snow to temperatures perennially above 10° C. In the whole of China, natural vegetation types have been highly modified by modern agricultural practices, and it is sometimes difficult to reconstruct previous vegetation patterns. This is particularly the case in areas of warm and mild climates, which are well suited for agricultural practice. For the most part, only montane shrubland and alpine meadow occupy their real niche and remain untouched by modern agricultural activities.

4.2.1) The Vegetation of Sichuan

Compared to Yunnan, relatively little is known about the natural vegetation of the low lying areas of the Sichuan Basin. The Sichuan Basin has been intensively cultivated for at least the past 2000 years and retains little if any of its original flora. On current maps of vegetation, this entire area is marked as agricultural land (Wu 1980). A few areas in the Sichuan Basin support remnant patches of the climax forest vegetation. Lands dedicated to temples such as Dazushan and holy mountains like Mt. Emei can offer us clues to what the flora of the ancient Sichuan basin may have been. Unfortunately the primary vegetation on Mt. Emei starts at only 750 m, thus at an altitude that is higher than that of the rest of the Sichuan basin (Tang and Ohsawa 1997). This area corresponds to an evergreen broad leafed forest zone, with a tree canopy dominated by members of the Lauraceae family and *Castanopsis*. Paleobotanical data (see

discussion below) as well as an analysis of climate patterns tend to support the fact that the Sichuan Basin was covered by an Evergreen broad leafed forest (at least between 3600-3400 BP and 2600-900 BP) (Li 1980; Luo, et al. 2008).

An analysis of the vegetation in the higher altitudes of Mt Emei provides a picture of the vegetation present in the southern mountain chains surrounding the Sichuan Basin. Compared to the mountains of the north and west, this area is marked by a warmer, more humid climate. Mixed evergreen and deciduous forest begins at higher altitudes in this region, between 1500-2000 masl. Here the evergreen vegetation is dominated by *Lithocarpus*, *Camellia*, *Choroespondias*, *Prunus* and *Eurya* (Tang and Ohsawa 1997). Between 2000-2500 masl, deciduous trees are replaced by conifers and *Acer*, *Abies*, *Tsuga* and *Taxus* dominate the assemblage along with *Lithocarpus*. Wild kiwi fruit (*Actidinia* sp.) and was also present in the sub-layer. A conifer-dominated forest begins at 2500 masl and reaches up till 3099 masl. Here the forest is dominated by *Abies* sp., although mountain ash (*Sorbus* sp.) that has an edible fruit was also present.

The climate becomes colder and drier to the northwest of the mountain ranges. In Jiuzhaigou, vegetation characteristic of much colder climates dominates (Winkler 1998). Between 2000-2700 meters, a montane mixed forest belt of deciduous trees such as different species of maple (*Acer* spp.), oak (*Quercus aliena*), conifer trees such as (*Pinus armandii*, *P. tabulaeriformis, Picea* spp., *Tsuga* spp.) as well as Juniper exists (Winkler 1998). At an altitude of 2700-3200 m an alto-montane bamboo cloud forest exists, where higher rainfall leads to the presence of bamboo and increased numbers of epiphytic cover. The primary forest vegetation is composed of spruce (*Picea* spp.), fir (*Abies* spp.,) larch (*Larix* sp.), at 3200 m this is supplanted by an alto-

montane rhododendron forest, where bamboo is replaced by rhododendron. A sub-alpine forest zone dominates the higher zones (3500-3800 masl) and here the numbers of juniper increase (Winkler 1998).

4.2.2) The vegetation of the Yunnan-Guizhou Plateau

The geophysical characteristics of the Yunnan-Guizhou plateau have led to a wide range of ecotypes being present in this region. The lowest point in Yunnan province is 76.4 m above sea level on its southeastern edge, while the highest point is over 6000 m at Kagebo peak. The topographic slope from northwest to southeast has created a large temperature gradient across the plateau (Li and Walker 1986). Tropical evergreen forest occupies only the most southern part of the province west of the Ailaoshan. Its maximum altitude of occurrence ranges from 100m in the east to 1500 m in the southwest. Humid tropical rainforest occurs only in Southeast Yunnan in Hekou and Jinping counties below altitudes of 400m. The flora of both of these areas is most like Southeast Asia.

Annual mean temperatures range between 22-26 °C and the mean of the coldest month is 18 °C. This area experiences large amounts of rainfall, measuring over 2000mm per year. A seasonal tropical evergreen forest is found in southern Yunnan in basins below 100m, however, this type of forest experiences cooler and drier winters. Here the annual mean is slightly cooler ranging between 20-25 °C (Li and Walker 1986).

One of the most widespread types of forest in Yunnan is the subtropical evergreen broad leafed forest. In central Yunnan, this forest grows between 1000-2000 meters above sea level. Moving

southward this forest can be found at altitudes as high as 2800 meters above sea level. These forests are dominated by different types of oak trees (such as *Cyclobanalopsis* and *Lithocarpus*) as well as by members of the chinkapin family (*Castanopsis* sp.), all of which contain edible fruit. When anthropogenically disturbed, this forest is replaced by the Yunnan pine tree (*Pinus yunnanensis*), which also produces edible pine nuts. The large numbers of edible nut species present in this area provides some suggestions as to the kinds of foods that may have been consumed by the foragers that once inhabited this region. This forest grows in areas with a strong seasonality and whose annual mean ranges between 13-18 C. Areas with this forest rarely see temperatures below 0 and the mean of the coldest month ranges between 3-8 ° C.

Subtropical evergreen sclephyllous forest is found on the slopes of the Jinsha river valley. Winters in this area are dry and cold and experience snow. In the montane forests the annual mean is below 10° C, whereas in the lower reaches of the valleys, this warms to 15-18° C, and only milder frosts are experienced. Rainfall in this region is low and only ranges between 700-900 mm. Subtropical deciduous broadleafed forest covers small areas of Yunnan and is composed primarily of different species of oak tree.

Two types of secondary forest are present throughout much of Yunnan. These are largely due to human disturbance, making it difficult to estimate what kind of vegetation occupied this area in the past. Secondary forest regions comprise subtropical conifer forest dominated by *Pinus yunnanensis* ranging from 600-3500 masl. Another type of pine tree, *Pinus armandi* is confined to areas of higher altitude (2000-3000 masl). Subtropical evergreen shrubland also occupies a large area of Yunnan.

A montane conifer forest is only found in the northwest of the province, where it grows above 2700 m in altitude. *P. densata* is an important type of pine in this forest and is often accompanied by *Abies*, *Betula* and *Larix* sp. *Tsuga* and *Larix* dominated forests are other important high altitude forest types. Montane shrubland covers areas of over 4000 masl and is often dotted with areas covered by alpine meadow, where *Kobresia* meadow is dotted by wild strawberries, *Potentilla* sp. A savannah ecotype occupies the low lying basins of some of the rivers below 1200 masl, where annual rainfall is low such as the Yuan River basin, the Nu and the Lancang. In upland Guizhou province, this vegetation pattern follows similar altitudinal trends.

4.2.3) The Vegetation of Tibetan plateau:

Between the Chengdu Plain and the highlands of the Tibetan Plateau a wide range of different vegetation and climatic zones are present. The type of vegetation is directly related to altitudinal changes (Xu, et al. 2006). Several factors change the range of the extent of vegetation on the Tibetan plateau. Due to the heating of the mass of the Tibetan plateau, its effective heat is greater than on mountains of the same latitude and altitude (Chang 1981). Higher levels of solar radiation also contribute to it having a higher temperature. For these reasons, the altitudinal limits of vegetation types are much higher on the plateau than on mountains in Yunnan or Western Sichuan, and both the snow line and tree line are between 900-1500 masl higher than in other areas. The mountains surrounding the plateau form a rain shadow that leads to an arid to semi arid climate on the plateau itself (Chang 1981). The majority of the plateau is dominated by low and high shrub tundra in the eastern half of the plateau and by graminoid and forb tundra in the western part of the plateau (Ni and Herzschuh 2011). In the southeast this is interspersed with

an evergreen taiga montane forest. Vegetation growing in warmer conditions is only found in Bhutan, where a deciduous montane forest grows.

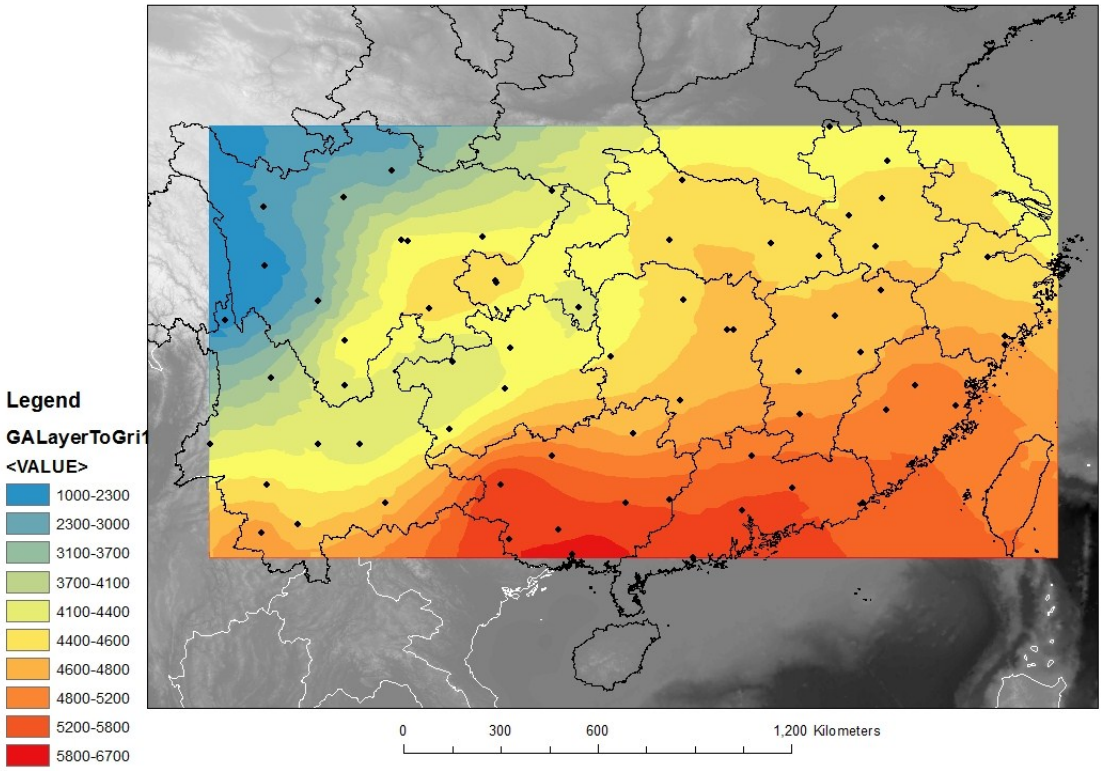

Figure 4.1 Growing degree days using a circular model on a 10 °C base for Southwest China.

An analysis of accumulative growing degree days shows a marked trend in temperature between eastern and western south China (Figure 4.1). Although much further south in latitude, the altitudinal effect of the Three Gorges, Western Sichuan highlands and the Yunnan-Guizhou plateau mean that temperatures are much lower here than in areas of similar latitude in southeastern China. Except for the southern tip of Yunnan, this region shows temperatures similar to that of latitudes that are much further north in northern China.

4.3) Ancient Climate

The present climate of southwest China does not reflect past conditions. It is therefore necessary to consider the effect that climate change has had on past agricultural production. A number of macroregional trends separate the climate of the earlier Holocene from that of today. Bond (1997) has proposed that climate fluctuations occurred in the North Atlantic approximately every 1470+-500 years throughout the Holocene (Table 4.1).

Table 4.1 "Bond events" recorded on a global scale.

No	Date ka	Description
0	0.5 ka	Little Ice Age
1	1.4 ka	Migration Period
2	2.8 ka	1st millennium BC drought
3	4.2 ka	4.2 kiloyear event, maybe triggering collapse of Akkadian empire
4	5.9 ka	5.9 kiloyear event
5	8.2 ka	8.2 kiloyear event
6	9.4 ka	Cold event in China as well as Norway
7	10.3 ka	
8	11.1 ka	Transition from the younger Dryas to the Boreal

Over recent years, a growing body of evidence has allowed us to better reconstruct changes in climatic conditions during the Holocene in China. See Table 4.2 for a summary of this data in Southwest China. One common trend discussed in all papers is the presence of a global climatic optimum during which temperatures were warmer and where higher precipitation values were common (i.e mid Holocene Megathermal or Hypsithermal). The dates of this trend are still

debated, however dates for its beginning range from 9000-7500 BP, and it is hypothesized to end between 5000-2500 BP (Shi, et al. 1993). In particular, between 8700-8500 BP, the temperature in western China appears to have increased by 4-5 ° C (He, et al. 2004; Shi, et al. 1993). However, the exact start and end dates of this transition to warmer temperatures are unclear (He et al. 2004).

During this period, Shi et al. (1993) argue that two periods of time represent substantial warming events: between 8500-8400 BP and 3000-2900 BP. Prior to the earlier warm event, a marked cold event appears to have occurred c. 8900- 8700 BP and another cooling event appears to have occurred c. 3000- 2900 BP. Another important trend involves the arrival of maximum monsoon strength during the early-middle Holocene (6000-4800 cal. BC). According to An et al. (2000) maximum precipitation in Northern China took place between 8000 and 5000 BC, however in the middle and lower reaches of the Yangzi River Valley this occurred between 5000 and 3000 BC.

Another major event is known as the "Holocene Event 3" or the "4.2 kiloyear BP aridification event" during which cooler and drier temperatures prevailed (Arz 2006). This event has been implicated in the cultural collapse around the world (Davis and Thompson 2006; deMenocal 2001; Gibbons 1993; Staubwasser, et al. 2003; Wu and Liu 2004). In addition to this event, there appear to have been several periods of time during which weak summer monsoons affected northern Asia. These include arid events around 5000-3000 BC, 1000 BC and around 1000 AD (Shi, et al. 1993).

However, using data from one region to apply it to another may not present a picture that is representative of past climate trends (He, et al. 2004). Several problems exist in interpreting different paleoclimatic records. The first of these issues is that large uncertainties exist in the absolute and relative timing of these records (Haam and Huybers 2010). How these larger patterns affected the weather in southwestern China is not entirely clear. For instance, it is unclear if a weakening of the monsoon in one area of China corresponds to a weakening of the monsoon in another. For instance, while weak summer monsoons may have caused droughts in north China, they could have had the opposite effect in southern China and led to increase rainfall (Wu and Liu 2004). In addition, it is also difficult to understand what kind of affect the changes recorded imply for surface temperatures. While studies based on pollen or botanical data can be used to infer that differences in temperatures based on vegetation composition, it is more difficult to relate changes in isotopic values (which related to precipitation) in ice cores and stalagmites to changes in surface temperature. In the discussion below, I summarize the multi-proxy evidence for climate change that exists for the area of Southwest China. This gives a rough estimate of when major reversals in climate change for this region appeared to have occurred.

In terms of Southern China, a few points of regional climate exist that can help us reconstruct how these events affected weather patterns in southern China (Figure 4.2).

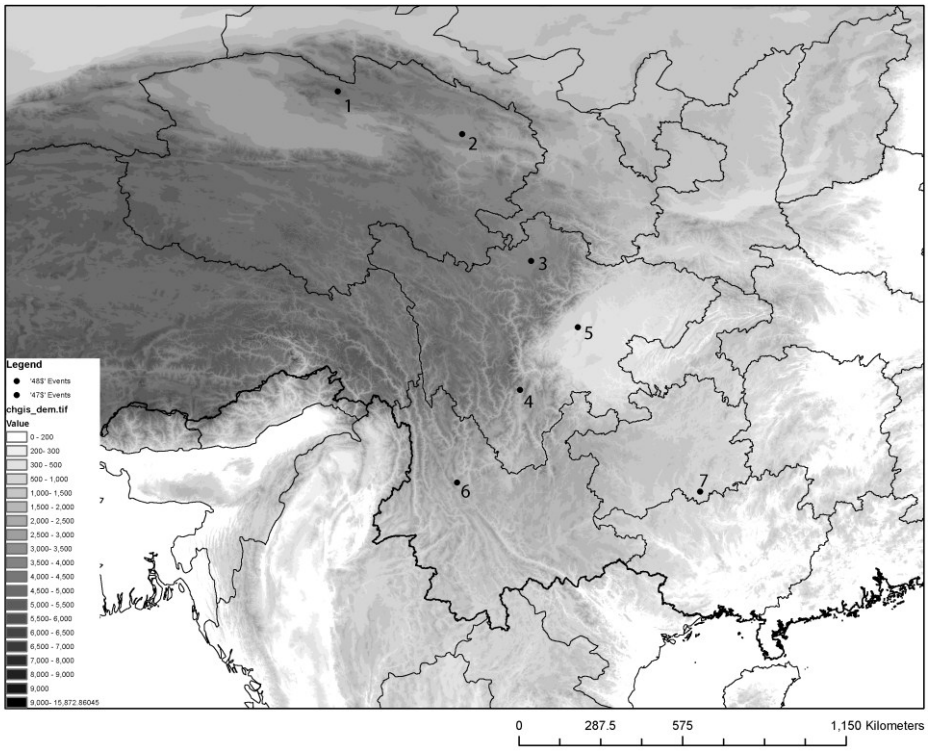

Figure 4.2 Paleoclimate records discussed in the text 1.) Dunde, 2.) Qinghai Lake, 3.) Hongyuan Peatbog, 4.) Shayema lake, 5.) Jinsha, 6.) Erhai Lake

Oxygen isotope research has been carried out at the Dongge stalagmite in Guizhou province (Dykoski, et al. 2005). Growth rings with large amounts of the heavy stable isotope, O^{18}, indicate years of weak summer monsoon and less rain. On the other hand, growth rings with small amounts of O^{18} indicate that there was a stronger summer monsoon with more rain. However, O^{18} values are also related to temperature. The concentration of O^{18} in precipitation decreases with temperature, hence when the temperature is low, O^{18} levels should also be low and when it is high, O^{18} levels should be high. Contrary to stalagmite records in other areas of China (Cai, et al. 2010; Overpeck, et al. 1996; Wei and Gasse 1999), the Dongge stalagmite does not show a gradual decline in monsoonal intensity during the Holocene. Instead, it shows a series of sharp drops. A well documented shift towards heavy values of O^{18} occurs between 9200 and 8200 BP

indicating years of weak summer monsoon. A drop in heavy values indicating years of strong summer monsoon occurs around 5650+-70 BP (4500-4400 cal BC), followed by a trend towards heavy delta O^{18} levels that last 400 years (until 4000 BC). This corresponds closely to trends seen in other parts of the world at the same time such Africa and also marks the end of the African Humid period.

The Dongge stalagmite shows another increase in O^{18} values and an increase in monsoon intensity that takes place around 3550+-59 BP (or 1972-1800 BC). This event correlates with the beginnings of Holocene Bond Event 2 from ocean cores in the North Atlantic (Dykoski, et al. 2005). Interestingly, these monsoonal patterns appear to have affected northern and southern China very differently, and the O^{18} record from the stalagmite in Jiuxian cave in the Qinling Mountains shows a different pattern. Here an increase in O^{18} values or a decrease in monsoonal intensity occurs between 4.85 ka BP (3600 BC), 4.6 ka BP (3300 BC) and 4.5-2.5 ka BP (3200-600 BC) thus quite a bit later than what is recorded in the Dongge stalagmite (Cai, et al. 2010). As these mountains form an important barrier to monsoonal patterns, I mostly consider the evidence from Dongge as being relevant to this study.

Pollen cores from Southwestern Sichuan can provide us with an idea of the climatic conditions for the early Holocene in this region (Jarvis 1993) (Figure 4.2). The pollen from lake Shayema in Mianning county (2400 m above sea level) shows that during the period ranging from 7100-5800 BC climate in this area warmed and cold tolerant species such as Hemlock (*Tsuga* sp.) declined to be replaced by birch (*Betula* sp.), deciduous oaks, and pines. Cold conditions return and Hemlock dominates the landscape again between 5800-2000 BC, after which point the climate

returns to warmer conditions. Signs of human disturbance at the site begin around 1000 AD in the form of increased presence of grasses and other disturbance taxa as well as the deposition of fine laminas of clay associated with erosion. Pollen from buckwheat (*Fagopyrum* sp.) increases, and other grasses and agricultural weeds increase considerably during this period of time, suggesting that this erosion is associated with agricultural activity. Buckwheat is still grown as a crop in the area (Jarvis 1993).

Several studies have been carried out on pollen data from Erhai lake in Yunnan Province. They show that cool climatic conditions with weak summer rainfall characterized the area between 10950-9750 BC. Pollen from hemlock and birch, as well as from deciduous acorns like *Cyclobanolopsis*/ *Lithocarpus* are present throughout this period of time (Dearing, et al. 2008; Shen, et al. 2006). Between 9750-6430 cal. BC, a pattern of rising temperatures with drier winters and wetter summers. This increase in winter droughts led to an expansion of dry herbaceous taxa. From 6430-1970 BC, records show evidence for the arrival of warmer conditions with the Holocene climatic optimum. They estimate that during this period of time temperatures were roughly 2-3 °C higher than modern temperatures in Southern China.

This period also contains the first evidence for anthropogenic manipulation of the landscape. Although this is at odds with the current archeological evidence, around 4100 BC the appearance of taxa associated with forest clearance such as *Artemesia*, *Plantago*, Chenopodiaceae and Poaceae increase, while deciduous tree pollen and hemlock pollen decrease (Dearing, et al. 2008; Shen, et al. 2006). Previous work done on the Erhai data suggested that the onset of agricultural activity dated to later: c. 3500 BC (Z. Zhang, et al. 2000) or to 2800 BC (Dearing, et al. 2008).

Xu (1987) reports a decrease in Oak around 2500 cal BC associated with charcoal. From 1970 cal BC, a sharp increase in the Poaceae as well as *Juglans* (walnut), *Olea* and Moraceae species might indicate an agricultural landscape with the possibility of some arboriculture. Other evidence, however, also indicates that a cooling event may have taken place during this period of time as there is an increase in pine pollen, accompanied by a decrease in *Cyclobanalopsis* and *Lithocarpus* sp., both of which prefer warmer temperatures. As pine pollen is capable of travelling hundreds of kilometers, they argue that this increase in pollen was related to their growth in surrounding areas following climatic cooling trends. However major increases in disturbance taxa appear only around 200 BC, which correspond to the movement of the Han empire into this area. Around 140 BC they note another increased episode of deforestation, and by 1000 AD the increase in grass reaches an all time high. This corresponds to the expansion of the Dali state on the western bank of the lake (Shen, et al. 2006).

In the Chengdu Plain, one study of pollen analysis has been carried out. Samples ranging from 2400-800 BC were taken from the site of Jinsha in Chengdu City (Luo, et al. 2008). In the earliest layers of the site (between 3800-3600 BP), the authors argue that the landscape was characterized by a subtropical evergreen broadleaf forest containing trees from the magnolia family, Oleaceae family, as well as two species of oak tree. Spores from a number of species of ferns, including polyploidiaceae ferns characteristic of rainforest environments were also present during this period of time indicating that there may have been substantial forest cover in the area. Concurrently, large amounts of grass and Cyperaceae are present in the record at this time, however, indicating that open and disturbed land also existed around the site. Pollen from elm

and pine are also present, however given the ability of these to travel over long distances this is difficult to interpret.

Between 3600-3400 BP, a switch occurs to a deciduous broad leafed forest with evergreen trees, such as *Elaeagnus* or Silverberry, which often contain edible fruits. Magnolia, Oleaceae and oak pollen undergo a huge decline during this period of time. Grass pollen also undergoes a decline as do some species of ferns. However the authors interpret this period as being one of overall warm temperatures. Between 3400-2600 BP species associated with cooler temperatures are present in the pollen assemblage. Species such as *Elaeagnus,* and *Cyclobanalopsis* fall out of the record, as does *Ulmus* sp. Warmer temperatures are believed to return between 2600-900 BP, which is followed by an additional cooling event.

Another recent study at the Jinsha archaeological site (Wen, et al. 2012), used stable Carbon and Oxygen isotopes, total organic carbon, free iron oxide and particle size distribution in sediments and fossil teeth. A sediment column identical to that published by Luo et al (1998) was taken from Jinsha. The authors examined the ratio of C3/C4 isotopes in the column according to the logic that the ratio of C4 to C3 plants increases with a drier and warmer climate. Correlating this study with a study of total organic carbon and free iron oxide they conclude that an increase in C4 plants correlated with a cooler and drier climate. The total organic carbon proxy used by the authors assumed that larger amounts of decomposed biomass would be present in assemblages dating to periods of time that are warmer and wetter, however, this measure does not take into account site formation processes. Free iron oxide is supposedly a measure of pedogenesis and is supposed to be correlated with increasing moisture. However, here again, this measure does not

take site formation processes into account. It is thus difficult to interpret these results. This paper also includes isotopic analysis of human and animal teeth (7 samples) and finds that both humans and wild boar consumed primarily C3 plants, which is not surprising. One elephant tusk was highly enriched in C3; however, the implications of this study are unclear. Oxygen isotopes were also measured with the goal of evaluating their relationship to temperature based on previous studies which argue that δO^{18}_{PO4} values should increase by 0.5% with a 1 C increase in temperature. This analysis supposedly points to the fact during the Shi'erqiao period temperatures were overall warmer than today.

On the Tibetan Plateau a number of proxies for changes in Holocene climate exist. They include studies on peat bog records from Hongyuan district in Eastern Tibet (Yu, et al. 2006). This study reports a warming trend between roughly 11.5 ka to 8.2 cal BP. The authors of this study argue that the phase between 8.2 and 5.9 cal BP is marked by an increased winter monsoon but a decreased summer monsoon. In total, seven cold events recorded in these peat bog occur at about 1.5, 3.5, 5.2, 6.2, 8.0, 9.6, 10.1 and 11.1 cal. BP. However, the 6.2 event represents the largest climatic fluctuation. They argue that after 5.5 cal BP, the climate in general grows cooler than the Holocene climatic optimum. Another important record from Tibet comes from the Dunde icecore near the Qaidam basin (Thompson, et al. 1990). Between 4200-850 BP, the record is marked by an overall warming trend with one noticeable cooling trend that takes place at roughly 1800 BP.

Table 4.2 Summary of Holocene Climate Trends in China with a focus on Southwest China

Date (Radiocarbon years)	Date (Cal BC)	Description	Reference
8900-8700 BP	8100-7700 cal BC	Cold event	(Shi, et al. 1993)
	8000-7000 cal BC	Cold event with maximum at 7400 cal BC.	Guliya icecore (Yang, et al. 1997); Erhai lake total organic carbon (Zhou, et al. 2007) ; Qinghai lake multiproxy study (Shen, et al. 2004) Dunde Icecore (Thompson, et al. 1990)
8700-8500 BP	7700-7500 cal. BC	Warming trend, increase of 4-5° C	(Shi, et al. 1993)
8500-8000 BP	7565-6950 cal. BC	Strong high temperature	From Dunde Ice core (Thompson, et al. 1990); Lake Bangong water levels in Tibet (Li 1983) Peat records from Eastern Tibet (Yu, et al. 2006).
7800 BP	6600 cal. BC	Cooling Event	(Thompson, et al. 1990) Dunde Icecore, Peat records from Eastern Tibet (Yu, et al. 2006)
7300 BP	6100 cal BC	Cooling Event	Dunde Icecore (Thompson, et al. 1990)
7200-6000 BP	6000-4800 cal BC	Holocene Optimum	Various proxies summarized in (Shi, et al. 1993) including Erhai lake(Dearing, et al. 2008; Shen, et al. 2006)
6000 BP	4800-4000 cal BC	Cold event	Guliya icecore, Qinghai lake Erhai lake
5650+-70 BP and lasting 400 years	4500-4100 cal BC	Decrease in monsoonal intensity	Dongge Stalagmite (Dykoski, et al. 2005)
	4000-3600 cal BC	Warming event	
4900 BP	3600 cal BC	Cooling event	Dunde icecore
4500-4000 BP	3200-2500 BC	Warming event (temperature may have been 3 C higher)	

Table 4.2 Continued			
4100-4000 BP	2500-2100 BC	Cooling event	Dunde icecore, Erhai lake pollen (Dearing, et al. 2008)
3550+-59 BP	1900 BC	Very marked decline in monsoonal intensity (also correlated with temperature decline)	Dongge Stalagmite (Dykoski, et al. 2005)
3200 cal BP	1200 BC	Cooling event	Erhai lake pollen (Shen, et al. 2006; Tang and Shen 1992)
1500- cal BP	500 AD	Cooling Event	Zoige Peat records (Yu, et al. 2006)

Summary

This chapter has demonstrated that unlike areas of similar latitude in eastern China, southwestern China contains a wide array of different ecological niches. While the Sichuan basin contains warmer and more clement temperatures it is surrounded by zones of cooler temperatures, higher altitude and more vertical terrain including the Three Gorges to the east, the Qinling mountains to the North, the Yunnan-Guizhou plateau to the south and the Hengduan mountain chain and foothills of the Himalayas to the West. A review of the current natural vegetation reveals that southwest China would have contained ample resources for populations of hunter-gatherers to subsist on. The patterns seen in the region today, would, however, have changed substantially in the past. An examination of multi-proxy data from pollen cores, icecores, stalagmites and soil samples reveals that climatic changes may have affected parts of southwest China at different times. Nonetheless, several major cooling and warming events can be outlined from this review of the literature: a.) A climatic optimum takes place in the region, sometime between 6000-4800 cal BC, b.) following this climatic optimum a cooling event takes place between 4800-4000 cal BC, c.) this is followed by a transition to overall warmer temperatures that last until d.) another

marked cooling event occurs somewhere between 2500-1900 BC. Given the patchiness of the current data and the lack of modeling carried out, it is difficult to understand how exactly each of these warming and cooling events affected surface temperatures in a given ecological niche and ultimately agricultural production. While we can use these as a rough guide to understanding the challenges that climate change may have posed to ancient agriculturalists, I was not able to factor these into an analysis of growing degree days as it was difficult to estimate by how much daily temperatures would have decreased or increased.

CHAPTER 5

DOMESTICATES IN SOUTHWEST CHINA: HISTORY AND PHENOLOGY

In order to map the ecological niches of the domesticates introduced to Southwest China, it is important to have an accurate understanding of each crop's phenology and how their phenological characteristics may have changed over time. This chapter begins by reviewing our current understanding of the domestication and spread and phenological characteristics of the main crops used in Southwest China. This chapter describes each of these for rice, foxtail millet, broomcorn millet, wheat and barley. While the phenology of rice, wheat and barley are relatively well understood compared to millets, it is important to note that very little work has been carried out on the phenological properties of traditional landraces of these crops in contrast to other crops such as maize (Adams, et al. 2006; Bockinsky and Kohler 2012).

5.1.) Rice (*Oryza sativa*)

5.1.1.) The Origins of Rice Agriculture in the Lower and Middle Yangzi

i.) Lower Yangzi River Valley

Recent debates on the origins of rice cultivation have led to a re-evaluation of the timing and locus of its emergence. Two main models have been proposed for the timing of rice cultivation and domestication. A first model argues that rice was domesticated c. 8000-7000 cal BC. Excluding some suspect pre-Holocene sites[4], this model argues that there is evidence for early

[4] While initial reports situated the origins of rice cultivation in China at late Pleistocene cave sites such as Yuchanyan (c. 16000-12000 BC) and Zengpiyan (c. 8000-5000 BC) (Yuan 2002; Zhang and Yuan 1998) recent re-excavations and continued analysis has considerably changed our understanding of the role of these sites in the origins of Chinese agriculture. For instance, systematic flotation at the site of Zengpiyan produced no rice despite a

rice exploitation at lower Yangzi River basin at sites such as Shangshan (c. 8000 cal. BC) (Jiang and Li 2006; Liu et al. 2007; Yuan 2002). Several lines of evidence have led the excavators of Shangshan to believe that the inhabitants practiced farming. They argue that unlike other early Holocene sites in southern China, the inhabitants of this site were already relatively sedentary and had abandoned living in cave environments in favor of open air permanent pile dwellings. In addition, the presence of grinding stones suggested a certain degree of sedentism (Jiang and Li 2006). The authors argued that the rice at Shangshan may have been undergoing domestication based on the size of rice husk impressions, the fact that rice was used as pottery temper and the presence of rice phytoliths. Following the publication of the evidence from Shangshan (Jiang and Li 2006), this model was immediately criticized as lacking morphological domestication for domestication (Fuller, et al. 2007; Fuller, Qin, et al. 2008b). The discussion that followed has led to the use of more careful criteria for identifying domestication to be used in the study of ancient rice cultivation. An important result of this discussion is the recognition that identifying domestication by rice measurements alone is difficult and not always statistically reliable.

Ultimately, the critiques from Fuller et al (2007; 2008a, b; In Press; 2009) have led to a re-evaluation of the previous model, and it is now increasingly accepted that rice cultivation in the Lower Yangzi basin began somewhat later (c. 6000 cal. BC). A re-evaluation of rice spikelet bases from the site of Tianluoshan shows that traits associated with domestication, such as a non-

large variety of other paleobotanical finds (Zhao 2003). Recent re-investigation of the site of Yuchanyan provided no support for the notion that rice agriculture was being practiced alongside the use of early pottery (16300- 13430 BC) (Boaretto et al. 2009). Similarly, recent re-evaluations of phytolith evidence from the sites of Diaotonghuan and Xianrendong shows that these sites are representative of a hunting and gathering rather than agricultural tradition (Zhao 2010a). Until more solid evidence for rice exploitation is unearthed from late Pleistocene sites, we have chosen to eliminate these sites from our discussion.

shattering spikelet base, evolved between 4900-4600 BP (Fuller et al. 2007; Fuller et al. 2008a, b; Fuller and Qin 2010; Zheng et al. 2007). Over this period of 300 years, a gradual decline in the proportion of gathered foods such as *Trapa* species and acorns suggests an increasing reliance on agricultural products. A corresponding decline of oak tree pollen around the same period leads the authors of this later model to suggest that hunter-gatherers may have begun to cultivate rice when faced with a decrease in productivity of one of their major resources (Fuller and Qin 2010).

Earlier models believed that following its cultivation c. 8000-7000 cal BC, rice dispersed to the Central East Yellow River Valley sites such as Jiahu by 7000–6000 cal. BC (Jiang and Li 2006; Liu, et al. 2007). However, Fuller et al. (2007) argue that the rice grains at Jiahu do not show morphometric evidence of a trajectory towards domestication. Stable isotope studies carried out on a series of human bones from Jiahu revealed a C3-heavy diet, which was initially interpreted as being due to rice consumption (Hu et al. 2006). However, as Fuller et al. (2007) point out the consumption of a wide variety of wild foods (most of which are C3 plants) could also have resulted in the observed C3 values. Systematic flotation carried out at the site of Jiahu by Zhao and Zhang (2009) confirms this picture, and shows that rice formed only a small percentage of the foods exploited by the sites inhabitants. Other resources such as water caltrop, lotus root and acorns largely dominate the assemblage.

ii.) The Middle Yangzi River Valley

Another possible center for rice domestication lies in the Middle Yangzi river valley sites of the Pengtoushan culture. Compared to sites of the Lower Yangzi, very little systematic work has been carried out in this area. Over 100 samples were floated from the middle to late Pengtoushan layers (7500-6100 cal.BC) at the site of Bashidang (Hunan Sheng Wenwu Kaogu Yanjiusuo 2006). Large quantities of uncarbonized plant material were unearthed at the site from an ancient

river bed. Both carbonized and uncarbonized rice were unearthed. The report focused on trying to identify whether the rice belonged to *Oryza sativa indica* or *Oryza sativa japonica* or an intermediate type. Genetic research has now well established that rice was domesticated more than once, with separate origins for tropical monsoonal indica and subtropical marshland japonica (Chen, et al. 1993; Cheng, et al. 2003; Londo, et al. 2006). Genetic studies on modern wild rice show that haplotypes for *indica* exist among wild rices in Northeast India, whereas *japonica* haplotypes are found in wild rices in Southern China. *Indica* and *japonica* rice were domesticated separately from these wild progenitors in different areas of Asia. The finds of rice at Bashidang therefore could not belong to an *indica* variety of rice. The authors of the paper conclude that the rice at Bashidang does not conform to other known modern varieties of rice and give it a new taxonym of *O. sativa* subsp. *ancietica bashidang*.

Genetic evidence has shown no modern wild rice varieties contain the CC haplotype, which is present in *O. japonica*, suggesting that the wild rice varieties that were implicated in its domestication went extinct (Londo, et al. 2006). Based on their evaluation of the measurements published in the Bashidang report, Fuller et al. (2008a) suggest that these fall into the range of wild/immature rice, making it likely that the rice unearthed at Bashidang is an extinct variety of wild rice. Because of the early date of this work, the excavators did not use a small enough mesh to recover rice spikelet bases, making it difficult to comment on the status of rice in the Pengtoushan culture. Based on present data we cannot eliminate the possibility of a second center of domestication in this region. At any rate, by the time that the settlements of the Daxi culture were established in this region (c. 4000 BC) it is clear that their inhabitants were heavily reliant on rice agriculture (Xiang and Huang 1995; Nasu 2007). Zooarchaeology was also carried out at this site and subsistence appears to have been focused on the hunting of deer and fishing.

In terms of possible domesticates, water buffalo (*Bubalus* sp.), chicken and pig (represented by only three teeth) are also present.

5.1.2) Rice Genetics and Domestication

As mentioned, domesticated rice is generally grouped into two major subspecies or varieties: *O. indica* and *O. japonica*. These two varieties differ in their ecological adaptations. *O. indica* varieties are largely grown in lowland tropical areas in South and South East Asia and China. *O. japonica* varieties tend to be more adapted to temperate climates and are cultivated in both lowland and high elevation upland areas of south East Asia as well as temperate regions (Zhao, et al. 2010). Although landraces are quickly losing ground to modern hybrid varieties, many different varieties of rice have been grown in China historically. It is therefore difficult to comment on the phenological traits one would expect to be associated with ancient rice varieties with a great amount of certainty. Today, it is recognized that the domesticated rices, the *O. sativa* complex, is divided into two main domesticated species *O. sativa* (East Asian rice) and *O. glaberrima* (African rice)(Sweeney and McCouch 2007; Vaughan, et al. 2008). In addition, this complex contains five or six other wild species, including, *O. rufipogon*, *O. barthii*, *O. langistaminata*, *O. meridionalis* and *O. glumepatula* (Sweeney and McCouch 2007). Out of these, only *O. rufipogon* is found throughout Asia and Oceania, while other species are endemic to Africa.

It is clear that *Orzya sativa* was domesticated from the wild ancestor *O. rufipogon*. *O. rufipogon* can, however, be divided into two different complexes: *O. rufipogon* per se: a perennial species

that inhabits wetlands, and *O. nivara*: an annual species inhabiting more seasonally drought prone regions (Fuller and Qin 2009). These two wild species have been treated either separately (Crawford 2012; Fuller and Qin 2009) or as a single group (Londo, et al. 2006; Sweeney and McCouch 2007) in the literature. Other differences characterize these two species/subspecies: *O. rufipogon* is a perennial and not a very productive seed grower as, in wild stands, most of the plants energy is focused into vegetative tillering. In contrast, the annual *O. nivara* is adapted to producing large numbers of seeds and grows seasonally in areas flooded by monsoons (Fuller and Qin 2009). Although a single origin for rice has been argued (Vaughan, et al. 2008; Vaughan, et al. 2003) recent genetic studies suggest that *O. japonica* and *O. indica* varieties were the result of separate domestication processes from a wild ancestor (Londo, et al. 2006; Sweeney and McCouch 2007).

In a 2009 paper, Fuller and Qin (2009) have argued that *Oryza sativa* subs *japonica* was likely derived from the lowland perennial ancestor O. *rufipogon* and inhabited wetlands, while *O. indica* was derived from the lowland *O. nivara*. This potential scenario is bolstered by the fact that the distribution of wild *O. nivara* stands are largely confined to Southeast Asia and India (see Fuller 2012: Fig 1), while *O. rufipogon* populations are more widespread and the only wild population of rice in China, hinting that these may have been ancestral to populations of *O. japonica*.

Recent evidence has additionally complicated this picture and has shown that a hybridization necessarily occurred between a fully domesticated species of japonica and a semi-domesticated or wild proto-*indica* (Fuller, et al. 2011; Sang and Ge 2007; Sweeney and McCouch 2007).

These hybridization events may have taken place in Northern India (Fuller, et al. 2011). In particular, recent genetic evidence suggests that the universal non-shattering mutation *sh4* probably spread by hybridization (Sang and Ge 2007; Sweeney and McCouch 2007). In a more recent paper, Fuller (2012) argues this evidence shows that modern *indica* varieties are the result of this hybridization (Fuller 2012: Fig. 2). In addition, he argues that the high seed producing characteristics of wild proto-indicas did not encite hunter-gatherers exploiting this species to intensify its use. On the other hand, the low seed producing perennial *O. rufipogon* would have required intensive management practices for it to be a profitable food source for hunter-gatherers. Indeed, the same authors have argued that *O. rufipogon* species can be water stressed to induce the plant to produce higher seed yields (Fuller and Qin 2009).

Following the domestication of rice, it is known that the emergence of a non shattering spikelet would have allowed for easy harvesting, and it is presumed that rice would have had increased seed yields. How exactly these yields changed is, however, unknown. In addition, little is known about the ecological or phenological requirements of ancient rice cultivars in China or what varieties of rice these were. Genetic evidence, allows us to make several postulations. Genetic evidence has revealed that five main populations of domesticated rice exist: these include *O. indica*, *O. aus*, temperate *japonica* (syn. *sinica*), tropical *japonica* (syn. *javanica)* and aromatic varieties (Garris, et al. 2005).

Given the evidence discussed above it seems clear that *O. japonica* varieties of rice were ancestral to China. Throughout historical times, there has been a rich history of exchange and different varieties of rice have been introduced into China. It is unclear when exactly *O. indica*

varieties were introduced. The *Shuowenjiezi* (AD 100) contains both the words Geng dao 梗稻 (*japonica*) and 籼稻 Xian dao (*indica*),both words that have since been used to describe these varieties (Bray 1984). Genetic studies (see Garris et al. Figure 1) have shown that *aus* and *indica* varieties group within the *indica* complex, while temperate *japonica* species, tropical *japonica* species and *aromatic* sub populations group within the *O. japonica* complex. Most shared genetic material occurs between temperate and tropical japonica (Sweeney and McCouch 2007; Zhao, et al., 2011), suggesting that these groups are selections from a single genetic pool that have been adapted to different ecological conditions. In a 2005 study, the alleles at 15 monomorphic loci in temperate japonica were identical in size to tropical japonica, leading one to believe that temperate japonica rices may have been derived from tropical japonica (Garris, et al. 2005).This hypothesis is also supported by evidence that the average standardized allele size was greater in temperate japonica than in tropical japonica. One explanation for this is that adaptive pressure put on temperate varieties may have encouraged higher numbers of mutations (Garris, et al. 2005).

Both upland and lowland varieties of *japonica* and *indica* rices exist. As outlined by Fuller et al. (2011: Fig. 1), these can be grown in a variety of different environmental settings. Rice fields can be flooded (paddy or wet rice) or non-flooded (dry or upland rice).

Fuller (2012) has suggested that this may relate to the archaeological situation in several ways. As in previous articles, he argues that rices domesticated in China were *O. japonica*. Fuller and Castillo (In Prep) further postulate that these early domesticates were probably tropical varieties of *O. japonica*. He further argues that in some regions, rice may have led to genetic dead-ends with relation to the genetic lineages that exist until today. In particular, he argues that varieties of rice found in the archaeological record at Houli sites in Shandong may have constituted such a

dead end as no continuity is shown with later sites. He similarly argues that the contribution of the rice cultivated at Jiahu (7000-6000 BC) to later gene pools is also unclear. It is also possible that the rices grown during the Yangshao period in Shanxi represent another evolutionary dead-end as they disappear from the record during the Longshan period (Dorian Fuller: Personal Communication 2012). In this article, Fuller (2012:83) argues that foragers across China may have begun cultivating rice in more than one part of China and he outlines several important hypothetical events that could have contributed to the current rice genome. The first represents a northward dispersal of rice from the Yangtze River valley region into northern China that he hypothesizes involved a temperate *O. japonica* (Fuller 2012; Fuller and Castillo In Prep). This spread occurred by roughly 4000-3000 BC. This is supported by evidence from sites such as Nanjiakou (ca. 4500-3800 BC; Rice dates 3900 BC), other middle Yangshao sites, and Xishanping in Gansu (3000 BC). A table compiled by Fuller et al. (2011) indicates that the rice involved at this point at these sites was a grown in a wetland environment. Movement further north and south appears to have delayed until after 2500 BC. In Korea, there are few finds of securely dated rice before 1500 BC (Ahn 2010). Fuller et al. (2011:4) argue that any finds prior to 1500 BC are likely to have been of dry cropped rice. It is possible that upland varieties of rice may have moved first because of the high labor investments associated with paddy construction. Fuller (2011) also argue that early forms of rice cultivation in Japan were likely dry-field and the spread of paddy technology to this region only occurred c. 1500-1300 BC in Mumum Korea and in the Yayoi period in Japan (c.900 BC) becoming established in Japan at only c. 400 BC.
With regards to Southwest China, this thus leads us to ask the question of whether or not the varieties of rice cultivated by the inhabitants of this region were temperate or tropical or were of the upland or paddy variety.

Fuller (2012) has also argued that there is a relationship between rice morphometrics and environments. In particular, shorter grains tend to be found at high latitudes or high altitudes, and are typical of temperate japonica whereas tropical japonicas tend to have longer grains. He argues (Personal communication 2013), that lower Yangtze evidence increasingly shows a morphological differentiation taking place in rice towards a short-grained, more temperate morphology and a longer more tropical/basal morphology over the course of the Late Majiabang-Songze-Liangzhu (c.5000-2250 cal BC). In addition, (Fuller and Castillo In Prep) argue that the short grained morphology associated with temperate japonica begins to appear at sites such as Nanjiaokou and the middle Yangshao sites (c.4000-3000 BC).

5.1.3) Later introductions of rice to China

In addition to *O. indica* varieties of rices introduced c. 100 AD, other varieties of rice have been introduced to China over the course of history. An important group of rices are Champa or fast ripening rices. Chinese sources record that the kingdom of Champa had rice varieties that were able to cropped twice during the year as early as the first century AD (Bray 1984). Champa rice was introduced to China during the Song dynasty. Devastation from war in northern China led to an increasing reliance on the agricultural products of southern China during the Song dynasty (Bray 1984). A decrease in arable land in the North pushed population concentrations southward exacerbating the risk of famine. Following a large famine, an early ripening drought resistant variety of rice was introduced from the Champa kingdom in Vietnam. Champa rice had already gradually begun to spread northward from farmer to farmer, however in 1012 AD the emperor

organized a large shipment of Champa rice to the Lower Yangtse and Huai River valley from Fujian Province (Zeng 1998).

The introduction of Champa rice was a huge success and soon was grown in over 90% of the fields in the lower Yangtse (Ho 1956). Introduction of Champa rice lead to a huge increase in rice productivity in China allowing rice to move into upland areas and for double cropping and even triple cropping to be carried out in some regions. There is some confusion about whether Champa rice was an upland or lowland variety of rice (Barker 2011; Ho 1956). According to Barker (2011) recent genetic tests on a Champa variety of rice revealed it to be an Aus variety, which he interprets as being an upland variety of rice. Other sources (Zeng 1998) also interpret Champa rice as being an upland variety. Prior to the arrival of Champa rice it is possible that other early ripening rices may have been exploited in China. One of these varieties is known as *Huang-lu*, which is mentioned as early as 620 AD in the "*Qi Min Yao Shu*", and is said to have a growing period of only 60-90 days. In addition to Champa rice, it appears that other fast maturing varieties of lowland rice also began to be grown around the time of the Song dynasty and allowed farmers to expand into areas liable to waterlogging and flooding (Zeng 1998). This was motivated by a need not only to move rice upland, but also by the need to reclaim swamp land. One of these is described by Zeng (1998) as being Huanglu rice. Higher rice yields can also be achieved by transplanting, where rice is sprouted in a nursery and young plants are planted directly into an already flooded field.

5.1.4 Rice Phenology

a) Rice and temperature

Estimating a threshold temperature for rice is difficult, as different stages in plant development require different temperatures. In addition, the many different varieties of rice described above have different temperature requirements. Nonetheless some general principles characterize the phenology of the rice plant. According to Yoshida (1981), rice will not germinate at temperatures below 10 ° C. In fact, the optimum range for germination is much higher and ranges between 20-35° C. Temperatures at or below 10° C will kill the crop. A temperature of 12° C degrees is critical to seeding development and in general contemporary farmers will only plant rice outside once a temperature of 15° C has been reached. For upland rice, varieties can be planted outdoors once temperature reaches 13.5 ° C degrees, however for lowland varieties, plants cannot be planted outdoors unless the temperature has reached 15-15.5° C degrees. As is shown by Table 5.1, the optimum values for these ranges are much higher, between 20-35° C for germination. Additional studies carried out on varieties in Pakistan showed that almost no germination occurred in temperatures below 15° C (Peyman and Hashem 2010). During the pollination stage, subjecting rice to temperatures below 20° C can result in high percentages of spikelet sterility. Table 5.1 summarizes the critical temperature ranges required for rice growth.

Table 5.1 Response of the rice plant to the varying temperatures at different growth stages (after Yoshida 1981: Table 2.4).

Growth Stage	Critical Temperature (Low) (°C)	Critical Temperature (High) (°C)	Optimum (°C)
Germination	10	45	20-35
Seedling Emergence and establishment	12-13	35	20-30
Rooting	16	35	25-28
Leaf Elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of panicle primordia	15	_	_
Panicle differentiation	15-20	38	_
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

In China, experimental studies have been carried out to determine the growing degree days of different types of modern rice cultivars (Chinese Institute of Agronomy 2011). There is a lot of variation among different varieties of rice currently grown in China.

For early ripening varieties of *O. japonica,* which ripen in 120 days for a growing degree base of 10 ° C, an accumulated GDD of 2900 is required. For middle ripening varieties, with a growing season of 120-130 days, an accumulated GDD of 3000-3300 is required. Late maturing species on the other hand with a growing season longer than 130 days require an accumulated GDD of over 3300 (Chinese Institute of Agronomy 2011). Varieties of *O.japonica* rice adapted to northern China have slightly lower temperature requirements. For early ripening varieties with a growing season of under 130 days, 2500 GDD are required. For those with a 130-150 day season,

between 2500-3000 GDD are required. For late ripening varieties with growing seasons longer than 150 days, over 3000 GDD are required.

Varieties of *O. indica* that are grown in southern China, have yet again different temperature requirements. Early ripening *O. indica* (110-120 days) varieties require roughly between 2400-2600 GDD. Late maturing varieties with a growing season of between 120-130+ days require between 3000-3300 GDD (Chinese Institute of Agronomy 2011). Given the archaeological evidence discussed above it seems likely that the rices used in Chinese prehistory correspond to the longer season *japonica* rices and would have required a minimum of 2500 GDD. In reality, the cumulative GDD required by these species was probably even higher, as the modern varieties studied represent improved cultivars.

Estimates of rice ripening times, based on historical texts indicates that the numbers of growing degree days required by traditional varieties may have been even longer. According to Yoshida (1981), traditional tropical varieties of rice are usually planted in June or July and take 160-200 days to mature, and are harvested in November or December. Historical sources around the time of the Song dynasty indicate that prior to the introduction of Champa-type short ripening varieties, traditional varieties of rice required over 150-165 days for ripening of early varieties, and between 180-200 days for late varieties (Zeng 1998). This may mean that growing degree day requirements were even higher for these ancient varieties.

According to Zeng (1998), two varieties of early ripening rices were introduced to China during the Song dynasty. These include Huang-lu rice, which grows in wetland environments and has an extremely short growing season of 60-90 allowing easily flooded wetland/swamplands to be colonized. Champa (or zhan-cheng) rice could we planted in the highlands and is reported as having a growing of 100-110 days (Zeng 1998).

Studies on rice phenology have also been carried out in *O. indica* varieties in Bangladesh. Work was carried out on five different varieties: Swarna, Silkumul, Kataribhorg, Lal pajam and Sanla all of which belong to the *O. indica* complex. These varieties had a growing season of roughly 107-116 days from transplant to harvesting and required a total of between 1810-1918 growing degree days (10 ° C base) (Islam and Sikder 2011).

b) Photoperiod

As mentioned above, rice is essentially a short day plant, meaning that it requires relatively long periods of uninterrupted darkness to flower. Optimum photoperiod is the day length at which the duration from sowing to flowering is at a minimum. According to Yoshida (1981), the optimum photoperiod of most rice varieties is between 9-10 hours. Critical photoperiod is the longest photoperiod at which the plant will flower or the photoperiod beyond which it cannot flower. The critical photoperiod of most varieties ranges from 12 to 14 hours. Photoperiod in the tropics varies only by a matter of minutes. In the most northern limits of rice cultivation, however, a 6 hours difference in day length can occur. Tropical plants are shown to be extremely sensitive to variations in day length and Malaysia cultivars of rice were demonstrated to exhibit sensitivities to a day length difference of only 14 minutes, taking 329 days to flower when planted in the winter and 161 when planted in fall when day length was at its longest (Dore 1959). It is expected that as rice agriculture moved northward, a high selection bias would have also been placed on varieties that were less sensitive to photoperiod. Recent studies suggest that temperate *japonica* rices are relatively insensitive to photoperiod, lending support to the hypothesis that it

may have been these varieties of rice that were involved in the spread of rice agriculture outside the lower Yangzi (Zhao, et al., 2011).

It is believed that photoperiod may be an adaptation to the East Asian Monsoon (Oka 1958). Whereas the start of the rainy season can be somewhat unpredictable, its end is fairly fixed in time. Photosensitive varieties will flower even if they are planted late because they react to change in daytime length. However, non photosensitive varieties require a set growing time before reaching flowering stage and may be affected by water stress as they may have not reached maturity after the end of the growing season. Most traditional varieties in the tropics are sensitive to photoperiod (Yoshida 1981).

c) Water

Both upland (rainfed) and lowland (irrigated or paddy) varieties of rice exist (Fuller, et al. 2011). As a result, different varieties of rice will react differently to water stress or flooding. In irrigated varieties, when irrigation is provided, developments in plant growth are largely determined by temperature and solar radiation. It is difficult to generalize about the water requirements of irrigated varieties of rice as they are grown in large stands of water. This is easier to estimate in rainfed varieties, which generally are grown only in areas where annual rainfall exceeds 800 mm (Jacquot and Courtois 1987) or 1000 mm (Yoshida 1981). Water stress can reduce yield or damage the plant at any stage of growth, however according to (Yoshida 1981) the plant is most sensitive to water stress from the reduction division stage until heading. Too much water can also cause problems in lowland rice varieties and flood resistant varieties, are currently being developed to deal with this problem (Yoshida 1981).

d) Nutrients

Like any crop, rice requires a variety of trace nutrients. For irrigated or paddy varieties of rice, nitrogen is supplied in large part thanks to species that grow in the aquatic environment. In particular, *Azolla*, a species of acquatic fern, is often grown in alongside rice in paddies because of its ability to fix nitrogen from the atmosphere. In contemporary practice, rice paddies can be inoculated with *Azolla* that will bloom and prevent weed growth. The rotting material from *Azolla* then provides nutrients to the rice plant (Lumpkin and Plucknett 1980; Moore 1969; Wagner 1997). In addition, nutrients can be added to the paddy system by rearing different species of carp in the paddy fields, whose excrement adds additional nutrients to fields (Fuller, et al. 2011; Mackay 1995). Archaeological and written records suggest that this practice may date to as early as the Han dynasty. Clay models of rice paddy fields containing carp have been found in Hanzhong county, Shanxi, and depictions of rice paddy field systems containing carp are also present on funerary bricks in Han dynasty tombs in Sichuan province (Cai, et al. 1995).

Other factors that improve rice production include effective weed control. Controlling weed growth can improve yields removing competition with weeds for nutrients and sunlight. Aside from weeding, agricultural practices such as puddling and tilling can prevent weed growth. Puddling can be achieved by introducing water buffalos into the field and by allowing them to trample the soil. This has the effect of breaking weed seeds and pushes them further into the ground, thus disturbing their germination. Tilling has a similarly destructive effect on weed seed growth (Soerjani, et al. 1987).

e) Soil quality

Dry field rice is often cultivated in a slash and burn context where nutrients are derived from the ashes of burned down plants. Such fields tend to lose fertility over the years. In all paddy construction, heavy alluvial soils with slight acidity yield the best results whereas sandy soils will generally yield poor results. The creation of paddies themselves alters chemical composition and the structure of different soil layers (Bray 1994). This process is known as podolization, whereby mineral compounds are dissolved and carried down to the subsoil. Soils cultivated in this way tend to change in nature from well drained to water retaining and take on a grey color (Bray 1994). This transformation of soils requires a high initial labor investment and for several years these early fields will be less productive (Bray 1994).

f) Rice yields

Yield of a crop is measured in tonnes per hectare. Rice also differs from other cultivars in several ways. Rice plants produce a large number of tillers (up to 50) and each panicle produces a large number of seeds (up to 200 per plant). On average a given wheat or barley plant will only produce between 4-5 tillers and each head will only bear between 20-90 grains. Thus rice has a much higher seed to yield ratio (Bray 1984). However, it is unclear how this information on yield relates to ancient varieties or rice. Experiments carried out by Lu (2006) in harvesting wild rice revealed that *O. rufipogon*, which reproduces by tillering and not by seed, had remarkably low seed production. In Lu's (2006) experiment, panicles of wild rice contained relatively few grains, which ripened at different times and shattered into the water causing large amounts of seed loss. In total she was only able to harvest 1.3 grains per panicle in contrast to 82.1 grains per panicle from domesticated rice. An individual would have been required to spend between 8.7-10.2 hours every day gathering and processing wild rice in order to avoid starvation. Compared to the

2-3 hours required for harvesting wild yams or bamboo shoots, it seems that producing ancient wild rice must have been remarkably ineffective. This has led some to argue that low yields and high risk associated with cultivated wild rices may have meant that it could have first been exploited as a luxury food (Hayden 2011).

5.1.4 The Technology of Rice Agriculture in China

Different methods of rice cultivation require different technology. Upland varieties or rice require less investment in labor in general than lowland paddy varieties (Fuller, et al. 2011; Yoshida 1981). In upland fields, rice is generally sown as a part of a crop-rotation and is often sown after forests have been cleared and burned (Jacquot and Courtois 1987). Today only 13% of rice farming is carried out in upland contexts (Fuller, et al. 2011). In rain-fed rice, water levels can fluctuate according to season and growing period from dry to up to 50cm of water. Several different types of lowland rice cultivations systems exist. One can classify these by water level and by construction technique. In terms of water level: In areas where rice is irrigated, fully controlled floodwater is kept shallow (Fuller, et al. 2011). Some varieties of rice can also be grown in deepwater contexts where floodwater can rise to more than 50cm (even up to several meters) (Fuller, et al. 2011).

Historically, a number of different methods of paddy rice cultivation have been attested, each of which requires variable investments in labor.

Field types

a.) *Bunded fields:* Bunded fields are constructed by leveling out an area designated to be the rice field and by retaining small walls (bunds) around each field. Clay models of bunded fields are common throughout Han dynasty funerary objects (Bray 1994). This is the type of field currently used in the Chengdu Plain. These fields require relatively little labor to maintain other than repairing the bund. Farmers interviewed in the Plain reported that the bunded fields in which they grow rice have been present for their entire lives and they have not changed in structure (CPAS farmer interviews: Winter 2011). This kind of field is easy to create and maintain in river valleys or delta plains where water can be taped from streams and rivers.

b.) Poldered fields or dyked fields (Hutian): Fields enclosed by a high earth dyke that prevents them from flooding. Feature of low marshy regions, particularly the lower Yangzi. Often constructed around lake shores. These fields were small so that water from the marshes could be controlled. Bray (1984:114) suggests that these fields were primarily sown with huang-lu or quick ripening rice (60 days) that was able to be grown without worries of flooding. Zeng (1998) distinguishes between a *Hutian* (unprotected beds on the lake, where soil is built up to given them a higher level) and *Weitian* (beds that are protected from higher water by a dyke). In particular, it is argued that farmers around the Tai, Poyang and Dongting lake area began to exploit the lake in this fashion, following the exposure of good rice growing land during periods where water levels in the lake were lower in the 14th century. During this time, large portions of the Dongting lake were converted to dyked fields (Bray 1994). Today, this practice is still common around lake Dian in Yunnan. However, without short season varieties of rice, enterprises such as this were particularly risky as fields could easily be flooded (Zeng 1998). A text in the first century BC, the *Yue jue shu* refers to the construction of these fields near Suzhou

(Bray 1984:113). Other mentions occur in the Springs and Autumns period, and then increase in regularity up until the Tang dynasty, when they appear to be more commonplace (Bray 1994:34). By the 12th century most of the swampy lakes in the Yangzi delta had already been converted to poldered fields. It is likely that the construction of this type of field only became important when population pressure forced cultivation into previously unexploited marshland.

c.) Sand fields: are fields that are protected by reeds and made on the sandy banks of the Yangtse and Huai rivers. According to Zeng (1998), the presence of fast ripening varieties of rice were integral to allowing this kind of field to be successful as its water levels were highly variable.

c.) Floating fields (feng tian): Sometimes lake margins are too marshy for dyke construction. Reeds from Jiaobai (*Zizania acquatica*), an acquatic plant, are bound together to form paddies that float on the surface. These kinds of fields were frequently used on Taihu lake in Hangzhou and Lake Dian in Yunnan and are described in texts as early as the Jin dynasty (265-419 AD) (Zeng 1998).

d.) *Terraces:* (*ti tian* 梯田) Terraces in China are known as *san bao*: three fold conservers that prevent erosion, conserve soil nutrients and in many cases crops grown on them result in a higher yield. The first allusion to irrigated terraces in southern China dates to the Tang Dynasty, where *shan tian* are described by the general Fan Zhou among the Man tribes of Yunnan. Similar descriptions of terraced landscapes are provided by the Tang poets Du Fu and Zhang Jiuling (Bray 1984:125). These terraces are generally interfaced with stone for reinforcement, to retain run-off water, however, earthern walls can also be employed. In instances where a source of

water exists above these fields can be irrigated. Zeng (1998) argues that in their early form, these titian were not fully irrigated but rather were constructed to allow upland varieties of rice or dryland crops to be grown. Bray (1994:33) also suggests that this is the case.

Archaeological evidence

Despite the difficulty of identifying rice paddies archaeologically, there is some archaeological evidence for the ways humans created an aquatic growth environment in for rice in the past. The earliest rice paddies have been unearthed at the site of Tianluoshan, where they were identified by the presence of rice and associated weed flora phytoliths (Zheng, et al. 2009). The small scale of the excavations outside of the habitation area of the site has not revealed what form or shape was taken by these paddies. High numbers of weed flora present in the samples from these units indicate that fields may not have been tilled. Other rice paddies have been unearthed at the site of Chengtoushan, Caoxieshan, Zhaojiazhuang (Jin, et al. 2007), Tenghualuo (Song 2012) and Chuodun (Cao 2006; Cao, et al. 2006).

The site of Caoxieshan, in Jiangsu Province (c.4200–3800 BC), provides important evidence for the techniques by which early rice in China was cultivated. Excavations at the site revealed the presence of small fields, ovoid in shape, and measuring only a few meters in diameter. They are argued to have allowed the tight control of water levels and soil fertility, which were important aspects of early rice management as it became domesticated (Fuller and Weisskopf 2011).

At Chuodun (c. 4000 BC) similar rice paddies have been unearthed. These 46 rice fields took a variety of shapes, ranging from round to rectangular and their size ranged from 1.4 to 16 meters. The fields were surrounded by ridges implying that they were bunded fields. These fields were connected by outlets or ditches to small ponds for water control (Cao 2006; Cao, et al. 2006). The relatively high numbers of weed flora found in the samples from these fields leads Cao et al. (2006) to conclude that systematic tillage and weed clearance did not take place. More recently, other analysis at the site has argued that the high presence of charcoal within the fields indicates that burning took place to clear the field prior to planting (Hu, et al. 2013). Large numbers of potsherds were found within the field, indicating that waste from habitation sites may have been placed in the fields as fertilizer (Hu, et al. 2013).

At the site of Chengtoushan, evidence for rice fields has been unearthed from layers dating to the Taijiagang (4400 BC) and early Daixi period (4300-4000 BC)(Hunan Provincial Institute of Archaeology and Cultural Relics 2007). This rice field appeared to be relatively narrow (less than 2.7 m wide), but very long (over 20 meters). Fuller and Qin (2009) have argued that in combination with the walled settlement at Chengtoushan, higher labor mobilization would have been necessary to construct the large fields present at this site. In the Songze period (c.4000-3300 BC) in the lower Yangtze, larger fields appear in archaeological sites. Large fields have been unearthed at the site of Maoshan and Chenghu (Song 2012; Fuller and Qin 2009;Zheng 2010). At Zhaojiazhuang and Tenghualuo in the Haidai region, analysis has been carried out on rice fields dating to the Longshan period (2000 BC). At Zhaojiazhuang, these appear to have been large (over 220 m2 and were separated by bunded ridges (Jin, et al. 2007). At the site of Tenghualuo in the same area, ditches, pits and outlets for water were also discovered (Lin 2000).

In later periods of time in Japan, at the Hitaka site (6th century AD) thousands of small rectangular 2x2m paddies were preserved after being covered by volcano ash (Furukawa 1991).

Associated weed flora is one way of understanding whether or not a rice was grown in an upland or paddy environment and it appears that both upland and lowland varieties of rice have been grown in China throughout prehistory (Fuller, et al. 2011). In particular it is believed that prior to 1500 BC in Korea and Japan all varieties of rice grown were upland varieties and it was only after this date that paddy technology began to be wide spread.

5. 2) Broomcorn and Foxtail Millet

5.2.1) Evidence for the beginning of millet agriculture in Northern China

a.) Northwestern China and the site of Dadiwan

Both Bettinger et al. (2010; 2007) and Liu et al. (2009) have recently proposed that millet cultivation may have first arisen in the upland foothill desert margins to the north of the Yellow river sometime before 6000 BC as a means of dealing with increasing climatic instability. However, the paucity of archaeobotanical data means that it is difficult to determine the exact point in time at which these transformations occurred. Some of the earliest concrete evidence comes from Dadiwan, where eight carbonized grains of broomcorn millet were unearthed from the bottom of an ashpit that was dated to Dadiwan I layer (6500-5900 cal.BC) by two radiocarbon dates (Gansu Sheng Wenwu Kaogu Yanjiusuo 2006; Liu, et al. 2004). Stable isotope

evidence reveals that broomcorn millet was consumed (by both humans and the animals they raised as early as 5900 BC (Barton, et al. 2009a).

b.) The Central Plains

Sites of the Peiligang culture contain important evidence for understanding the timing of the transition to agriculture on the Central Plains. The Cishan site has played an important role in our understanding of the development of agriculture in the region. Cishan was excavated in 1976 and 1978, prior to the implementation of flotation technology in China. Domesticated pig and chicken (although there is little evidence to support this claim) were found at the site. Although very few carbonized remains were found at the site, shells of walnut (*Juglans regia)*, hackberry (*Celtis bungeana*) and hazelnut (*Corylus sp.)* were unearthed in large storage pits. Although no charred caryopses were found, areas of grey sediment that contained voids in the shape of *Setaria italica* were found in these pits (Hubei Sheng Wenwu Guanlisuo 1981; Tong 1984).

A recent paper has tried to push the evidence for millet cultivation at the Cishan site even earlier (Lu, et al. 2009). This article provides new radiocarbon dates for Cishan pushing the beginnings of occupation from 8000 BP to the Holocene boundary c. 10000 BP (Lu et al., 2009). Based on an examination of husk phytoliths and chemical biomarkers present in new excavation units, this paper concluded that between 10300-8700 BP the inhabitants of the site were primarily reliant on *Panicum* millet, and only after 8700 BP did tiny quantities of *Setaria* millet begin to appear (Lu, et al. 2009). While the title of this paper leads one to believe that the authors are dealing with the earliest "domestication" of *Panicum miliaceum*, a closer examination of the data reveals that this is a somewhat dubious claim. The authors provide convincing evidence on the basis of phytoliths for distinguishing between *Panicum* and *Setaria* millets, however, it is unclear whether their

reference collection is large enough to distinguish between wild and domesticated varieties of *Panicum* and *Setaria*. The authors also claim that the biomarker miliacin is exclusively found in the domesticated *Panicum miliaceum*, however a closer look at their methods reveals that they only checked for the presence of this compound in domesticated *Panicum miliaceum* and in domesticated *Setaria italica*. An examination of wild members of the genus *Panicum* is needed to make sure that this compound is only found in the domesticated species *Panicum miliaceum*. Despite the fact that these botanical remains were found in large pits, the authors were not able to show that the assemblage was in anyway undergoing domestication or originated from a food producing context. We agree with Bettinger et al. (2010a) that these earlier finds do not necessarily represent the remains of cultivated millets but may be the remains of plants gathered by a hunting and gathering society. As this report contained no contextual or cultural historical information about the types of pottery, stone tools or other cultural material found in association with these pits, it is difficult to understand how these finds relate to the later occupation known from the site.

Systematic flotation has not been carried out at other sites of the Peiligang culture. At the site of Peiligang itself, a few charred grains reportedly of foxtail millet (*Su*) were unearthed in ashpits that were dated to 6500-4700 cal BC (Henan Working Team No. 1 of IA CASS 1984) In another source, these same grains were identified as broomcorn millet (*Ji*) (Li 1984). Grains described as belonging to foxtail millet (*Su*) were also unearthed at the site of Shawoli in Xinzheng (Henan Working Team no. 1 of IA CASS 1983). At the site of Wuluoxipo (6000-5000 cal BC), four grains of foxtail millet were unearthed (Liu, et al. 2002).

c.) Xinglongwa and Eastern China

Xinglongwa culture sites (8200-7300 BP) in the Liao River valley of northeast Inner Mongolia contain important evidence for understanding the origins of millet domestication. These sites consist of carefully planned villages, which appear to have been occupied on a year round basis, and which may have been able to support populations of up to 100 individuals (Guo 1995). The organization of these villages and the apparent permanence of house structures seems to point to an agricultural lifestyle. Some (Li Smith 2005) argue that the paleopathology patterns of the skeletons at these sites seem consistent with foraging. These paleopathological criteria were, however, developed largely in the context of the Americas. Here, increased infection and dental wear are associated with the transition to agriculture. It is, however, unclear whether the lifestyle of early agriculturalists in China should show parallel patterns to that of other continents.

Finds of broomcorn and foxtail millet at sites of the Xinglongwa culture (6000-5500 BC) suggest a possible center of domestication in Northeastern China (Zhao 2005). Flotation at the site of Xinglonggou (dating to 8000-7500 BP) was carried out by Zhao Zhijun between 2003 and 2005. Over 1200 samples were processed, forming one of the most comprehensive sampling strategies for archaeobotany in China. To date, only a summary of finds from the site has been published (Zhao 2005), however it is clear that of *Panicum* caryopses (over 1000) formed the majority of the assemblage in the samples. By contrast only 10 caryopses of *Setaria* were unearthed. A photograph of the *Panicum* unearthed from the early Xinglongwa phases of the site appear to correspond to a wild type such as *Panicum ruderale* (Zhao 2005: Figure 4). It is unclear whether the *Setaria* unearthed belongs to a domesticated variety, however the specimens unearthed do already show the more rounded appearance and increased measurements similar to domesticated varieties. According to the report, both the *Panicum* and *Setaria* formed only a small (15%) part of an assemblage dominated by weed seeds (Zhao 2005). The lack of a full list of weed seeds

found in association with these finds makes it difficult to understand whether these "weed" seeds were plants that could have been gathered and consumed or brought into the site as weeds of cultivation with the millet harvest. Full publication of the report for this site will help clarify many of these questions. While stable isotope analyses point to the contribution of C4 plants in the diets of humans at the roughly contemporary site of Xinglongwa, they do not confirm the cultivation or domestication of millet (Zhang and Wang 2003).

Although much more evidence is needed to test these claims, the larger presence of broomcorn millet in earlier sites means that it may have been domesticated and exploited by hunter-gatherer populations before foxtail millet. The shorter growing season presented by broomcorn millet may have played an important role in this pattern. Bettinger et al. (2010a,b) has argued that hunter-gatherers in Northern China who were highly mobile and dependant on hunting began to carry out millet agriculture because it allowed them to partially maintain their mobility.

5.2.2) Broomcorn millet (Panicum miliaceum)

Compared to rice agriculture, relatively few experimental studies have been carried out on millets. Broomcorn and foxtail millet both have short growing seasons, and use water with high efficiency due to their C4 pathway. There have only been very limited attempts to model the growth of these plants in the past, or their relationship to water and temperature. In general, the phenology of broomcorn millet is better understood than foxtail millet as more experimental studies have been carried out on this species, due to its more widespread use today. In experiments carried out by Saseendran (2009), broomcorn millet required 89 days to physiological maturity. Anderson (1994) measured the number of growing degree days required

for broomcorn millet to achieve the flowering stage in the Central Great Plains of the United States. From their experimental studies it appears that broomcorn millet required between 900-1200 growing degree days (50° C base) to initiate flowering, regardless of planting date. What is apparent from this study was that the variation in number of days required for broomcorn millet to achieve maturity was directly related to temperature at germination and temperature throughout early development. When seeds were sown at an early planting date, the lower temperatures caused the plant to develop slowly, ultimately affecting its yield. For experimental plots where broomcorn millet was planted early (average daily air temp between 20 and 8°C), yields were 20% lower than when planted at the optimal date, and the plant required 64 days to reach the flowering stage vs. the 45 days required when the plant was sown at a time when daily temperatures lows were above 10° C and where daily high temperatures reached 30°C. A study carried out in Cordoba, Spain illustrates that another important difference exists between broomcorn and foxtail millet (Kamkar, et al. 2006). The cardinal temperatures required for successful germination were higher for broomcorn millet than for foxtail millet (Kamkar, et al. 2006), with broomcorn millet requiring temperatures above 20° C for germination to properly occur. Broomcorn millet has very little tolerance to frosts.

Table 5.2 Response of the Broomcorn Millet plant to the varying temperatures at different growth stages

Growth Stage	Critical Temp.(Low) (°C)	Critical Temp. (High) (°C)	Optimum (°C)	Days required	GDD required (10 ° C base)
Germination	10 (Kamkar, et al. 2006)	40 (Kamkar, et al. 2006)	30-40 (Kamkar, et al. 2006)	9-10	118-155
Tillering and growth				16-17	212-259
Flag leaf stage				22-24	305-363
Boot stage				28-31	398-467
Half bloom stage				34-38	492-572
Panicle differentiation				41-45	586-676
Anthesis				47-52	679-780
Ripening				53-59 (Cardenas 1983) 70-90 (Shanahan, et al. 1988)	772-884 (Cardenas 1983) 877-970 GDD (5° C base, Crown variety for forage)(May, et al. 2007) 2242-2130 (5.5°C base Mc Master et al.2011)

Despite its need for higher temperatures, broomcorn millet can grow well in conditions of low water. According to experimental studies in Pakistan, broomcorn millet performed better than other millets (including African millets) in terms of drought resistance (Seghatoleslami, et al. 2008). Although broomcorn millet has one of the lowest water requirements of any cereal,

according to Arnon (1972) this is not because of drought resistance but because of a short growing season.

5.2.3) Foxtail millet (Setaria italica)

Because foxtail millet is only rarely used as a crop today, studies carried out on it's phenology have been rather uneven, and very few have recorded the number of days required for foxtail millet to achieve full physiological maturity. Other characteristics have be used in experiments, such as days to head visible, days to flowering and the temperature required for optimal germination. Although Saseendran et al. (2009) carried out experiments on foxtail millet as well, the phenology of these plants were not observed to maturity but only to the stage of the head being visible. In two experimental plots, the heads of foxtail millet were visible at 75 and 57 days respectively. Both of these figures were substantially higher than what was observed with broomcorn millet, whose heads were visible at 50 and 49 days respectively in the same experimental plots. These results indicate that foxtail millet has a longer growing season than broomcorn millet. Other sources report foxtail millet as requiring between 60-120 days to achieve maturity, while broomcorn millet requires between 45-100 (Liu 2009). Despite the fact that broomcorn millet was found to be drought resistant, some studies indicate that foxtail millet shows greatest yields in both stress and non stressed conditions in Pakistan (Saseendran, et al. 2009). Foxtail millet also has a lower optimum germination temperature than broomcorn millet, meaning that it is more likely to successfully germinate in lower temperatures (Kamkar, et al. 2006). Using the program phenology MMS (McMaster et al.2011), I calculate that foxtail millet requires between 2082-2191 GDD (Table 5.3).

Table 5.3 Response of the foxtail millet plant to varying temperatures at different growth stages and growing degree days

Growth Stage	Critical Temp. (Low) (°C)	Critical Temp. (High) (°C)	Optimum (°C)	Days required	GDD required (10 °C base)
Germination	10 (Kamkar, et al. 2006)	38 (Kamkar, et al. 2006)	20-30 (Kamkar, et al. 2006)		
Tillering and growth					266 (Seghatoleslami, et al. 2008)
Half bloom stage					512-624 (McMaster et al.20115°C)
Anthesis				32-70 (Rao, et al. 1987)	1082-1194 (McMaster et al.2011 5° C)
Ripening					2082-2191 (McMaster et al. 2011) 5.5° C base)

Both foxtail and broomcorn millet are crops that benefit from being directly sown, and transplanting these crops results in injury. Given this and the fact that they can survive with relatively low water requirements, little labor investment is required when planting fields of broomcorn and foxtail millet.

5.3) Wheat (*Triticum* sp.)

5.3.1) History of domestication and genetics

Different varieties of wheat were domesticated in the Fertile Crescent beginning c. 8000 BC. From here, wheat moved rapidly into western and central Europe c. 4400 BC (Zohary, et al.

2012). Both wheat and barley appear to have taken a long time to move into East Asia. I do not summarize the history of wheat domestication here as it is well detailed in other sources (i.e (Zohary, et al. 2012) but focus on its spread to East Asia. In Central Asia, new evidence from the site of Begash shows that wheat was present in the Dzunghar Mountains of Central Asia c. 2500 BC (Frachetti, et al. 2010). In East Asia, the earliest evidence of wheat may come from the site of Xishanping in Gansu province, where wheat, barley and other domesticates were found in a context that supposedly dates between 2700-2350 BC (Li, et al. 2007). Another potential early find comes from the site of Liangchenzhen in Shandong province, where breadwheat was found in association with Longshan period pottery (2600-1800 BC)(Crawford, et al. 2005). Unfortunately, no direct dates were carried out on the wheat in these contexts so it is difficult to assess the validity of these finds. Securely dated evidence for wheat comes from the site of Donghuishan in Gansu and dates to c. 1700 BC with one early direct date in the 3rd millennium (Flad, et al. 2010). From here, wheat becomes established in Central Plains of China c. 1600 BC (Lee, et al., 2007) and moved to the Korean peninsula by 1000 BC (Crawford and Lee 2003). Little is understood about the movement of wheat southward, however both wheat and barley have been found by a Sino-Japanese mission doing research on the stone cist tombs at the sites of Benjiachi and Yanerlong in Western Sichuan (c. 1500-800 BC)(Sichuan Sheng Wenwu Kaogu Yanjiusuo, et al. 2012). The appearance of wheat c. 1600-1400 BC at Haimenkou makes it one of the earliest known in southern China (Personal Communication: Jin Hetian 2012). On the Tibetan plateau, the site of Changguogou has yielded both wheat *Triticum sp*. (appears to be free-threshing from the photograph) and naked barley (*Hordeum vulgare* var. *nudum*) in a context that appears to date to roughly 1471-850 BC (Fu 2001; Fu, et al. 2000) (See discussion in chapter 9). This makes several routes of introduction for wheat into the Yunnan-Guizhou

possible. While it may have followed broomcorn and foxtail millet down the corridors of western Sichuan, it is also possible that it may have been introduced across the Tibetan plateau or via southern foothills of the Himalaya.

Types of wheat can be distinguished by morphology, and genetics, and by growth habit. The following five biological species are recognized in the genus *Triticum* (Zohary, et al. 2012):

1.) A diploid *T. monococcum* (Einkorn wheat) (A^m A^m)
2.) Diploid *T. uratu* (AA): Comprised of only wild forms
3.) Tetraploid *T. turgidum* (Emmer wheat) (BBAA)
4.) Tetraploid *T. timopheevi* (GGAA) that was domesticated and grown in a small area of Georgia.
5.) Hexaploid *T. aestivum* (BBAADD) or breadwheat.

All of the wheat unearthed in contexts from East Asia appears to be of a compact variety of hexaploid breadwheat (*Triticum aestivum*). Breadwheat is the result of a cross between the tetraploid *Triticum turgidum* (BBAA) and a diploid wild grass *Aegilops tauschii* (DD). Today, domesticated tetraploid wheat is grown in Mediterranean type environments and it is hypothesized that the addition of the DD genome made hexaploid plants more capable of withstanding continental and cold winters. Zohary et al. (2012) suggest that this development facilitated the movement of wheat across the northern latitudes of Central Asia and also facilitated it's movement into Northern Europe where 6x *T. aestivum* types are also dominant in archaeological assemblages.

In terms of growth habit, both winter and spring varieties of wheat exist. Winter wheat is sown in autumn and grows during the winter. It requires a sufficient amount of cold stimulus and following this stimulus flowers in the spring once the days grow longer. Spring wheat on the other hand is sown in the spring and does not require a cold stimulus. Flowering begins to when the days get longer. Winter varieties are planted in September or October and require a period of dormancy before growing again in the early spring once a 5° C threshold is reached (FAO 2012). Spring varieties on the other hand are planted in March through April and are harvested in mid July through August. Wild varieties of wheat grown in the Fertile Crescent are believed to all be winter varieties of wheat, hence it is believed that the spring habit was a later development.

5.3.2) Wheat phenology

Because of the importance of this crop in world agriculture today, the phenology of wheat is known is great detail. Spring varieties of wheat have a growing season of between 100-130 days, whereas winter wheat requires between 180-250 days to mature.

Unlike broomcorn and foxtail millet it is well understood how stresses at different points in time of the plants lifecycle can result in variable yields. Different sources have listed different numbers of accumulated GDD for the emergence of a new leaf on the plant (phyllocron). The value may vary from about 70-150 GDD/leaf for winter wheat and from about 60-100 GDD/leaf for spring wheat (Klepper, et al. 1998). For winter varieties, high temperatures at grain filling stages can result in vastly reduced yields (Haider, et al. 2003; Klepper, et al. 1998; Nahar, et al. 2010).

There is however a huge amount of variation in different wheat varieties and their relationship with temperature. For instance with regards to germination, some winter wheat varieties are sensitive to high temperatures and will not germinate until temperatures are low (Edwards 2012; Lindstrom, et al. 1976). Winter varieties of wheat also have vernalization requirements. Cooler temperatures help the plants become weather hardy. During vernalization, the plant converts from vegetative to reproductive growth and the reproductive structures are developed. The vernalization requirement involves exposure to cooler temperatures for a required length of time. During this early stage of growth winter varieties can withstand temperatures as low as -20° C. Temperatures below 10 °C are needed to induce cold hardening and satisfy vernalization requirements; temperatures of -16 to -13.5 ° C are considered most effective. The amount of time required at these low temperatures is highly variable among species (Haider, et al. 2003; McMaster 1997). However, this frost resistance is lost during the active growth period in the spring and during this period of time, low temperatures will again damage the plant. While winter wheat varieties have a high frost tolerance (-20 ° C), spring wheat varieties have little to no frost tolerance (Klepper, et al. 1998; Saseendran, et al. 2009). For both varieties daily average temperatures above 10-12 °C are preferred if wheat is not to become a risky crop.

Table 5.4 Response of the Wheat plant to the varying temperatures at different growth stages

Growth Stage	Critical Temp. (Low) (°C)	Critical Temp. (High) (°C)	Optimum (°C)	GDD (0° C base)
Germination	1.2-1.6 (Seefeldt, et al. 2002) -9 or -10 C (Lecomte 1989)		12-25	80
Flag leaf stage	-20 C (for winter varieties)	30 (McMaster 1997)	15-20 C (both varieties)(Ed wards 2012)	2100
Heading	-1or -2 (Lecomte 1989)			2250
Anthesis	-2 -4 (Lecomte 1989)			2400; 476-728 (10 °C base) (Haider, et al. 2003)
Soft dough				2800
Ripening			15-20(McMaster 1997)	3500 (0°C); 848-1188 (10 °C base) (Haider, et al. 2003) (Haider, et al. 2003)
Other ripening estimates				(1869-2026)Spring wheat McMaster, et al.2011 5.5°C) (1907-2142) winter wheat McMaster,et al.5.5 °C)

Wheat requires more careful manipulation of water than millets and for high yields prefers between 450-650 mm of water. Water is essential during the early stages of germination and growth and during flowering. While the plant can withstand some water stress during the period

of vegetative growth, water deficits during the flowering period can have pronounced adverse effects on crop yield.

5.4) Barley (*Hordeum* sp.)

5.4.1) History and Genetics

Barley was domesticated around 8000 BC in southwest Asia in the Fertile Crescent from a wild, tough-rachised, two-rowed, hulled form (*H. vulgare* ssp. *spontaneum*) (Harlan and Zohary 1966). However, based on genetic data, there has been considerable debate during the past decade over the monophylly of domestic barley. In this debate, several separate origins for domestic barley have been posed, including Morocco (Molina-Cano, et al. 1999), Ethiopia and the western Mediterranean (Molina-Cano, et al. 2005), and Tibet (Xu 1982a). Although many genetic studies have supported a monophyletic origin (Blattner and Mendez 2001; Leon 2010 ; Li, et al. 2004), there is still discussion of Tibet being a separate center for domestication of barley based on early work by Xu (1982a) and Ma et al. (1987). This discussion was spurred following the discovery on the plateau in the 1980s of one of the wild progenitors of barley *H. spontaneum* (Molina-Cano, et al. 2002) Although more genetic work by Yang et al. (2008) has disputed this possibility, more recent articles point out that that the close relationship seen between modern varieties of Chinese hull-less and six row barleys could have been due to gene flow between wild populations of wild Tibetan barley, which grows alongside domesticated barley as a weed (Dai, et al. 2012).

Until archaeological evidence to support these hypotheses becomes available, this remains an interesting possibility.

Different barley cultivars exist. Barleys can be distinguished by differences in the arrangement of spikelets and by growth habits, two and six row varieties exist. In six row barley three kernels are formed at the node of each head whereas in two row types of barley only a single kernel forms at each node. Both hulled and naked forms of barley can also be differentiated.

Taketa et al. (2008) suggest, based on genetic evidence, that a monophyletic mutation of the *nud* locus caused the naked phenotype of barley. Helbeak (1959) suggests that naked barley spread quickly as a preferable form for food in suitable environments. However, Taketa et al. (2008) point out that the adhered glumes are actually adaptations to protect the grains from environmental stressors, such as drought or cold. Hulled barley tends to also be preferable for fermentation and fodder.

The domestication process of barley is marked by several key events (or series of events): (1) ca. 8000 BC non-brittle rachised hulled barley is cultivated in southwest Asia; (2) by 6500 BC six-rowed forms are cultivated, this mutation of the *Vrs 1* allele may have originated repeatedly in different geographic areas at different times (Komatsuda, et al. 2007; Leon 2010); (3) by 6000 BC naked barley (mostly six-rowed) is cultivated in southwest Asia and western India (Zohary and Hopf 2000).

Early examples of barley in Tibet and Nepal (>500 BC) are all naked (see chapter 9 for discussion). Outside of Tibet in far western Xinjiang, recent discoveries of barley in China have been naked-form as well; notably, 1300-900 BC grains from the site of Luanzagangzi in Xinjiang (Jia, et al. 2011).

5.4.2) Barley Phenology

Barley is also classified according to growth habit. Winter barley requires that seedlings are exposed to cold (vernalized). As with wheat, vernalization allows barley to produce heads and grain normally. Spring varieties of barley do not have this vernalization requirement and can produce reproductive parts without requiring exposure to cold temperatures. For both wheat and barley, the genetic mechanisms controlling for resistance to cool temperatures and vernalization appear to be closely related and could have evolved as these domestics were moved into areas of cooler temperatures (Fowler, et al. 1996). Wheat and barley plants are most susceptible to damage from frost in the early and late winter and early spring when plant are still young (Ventskevich 1958) During flowering and grain development, frost damage reduces the number of kernels per spike. For cereal crops the FAO (2012) lists the following resistance to freezing: Rye> Bread Wheat> Triticale> Barley> Oats and Durum wheat. In recent experiments, barley and wheat have similar types degrees of frost tolerance, up to -7 °C, after which barley does not survive (North Dakota State University 2012).

Table 5.5 Response of the barley plant to the varying temperatures at different growth stages using the Feekes scale

Growth Stage	Critical Temp. (Low) (°C)	Critical Temp. (High) (°C)	Optimum (°C)	GDD required (5 °C base)
Germination	4.4; -7 or -8 (Ventskevich 1958)		12 (Stoskopf 1985)	76 (Stewart and Dwyer 1987)
Main shoot plus 1 tiller	Seedlings killed at -8C (Stoskopf 1985)			455
Main shoot plus five tillers				534
Flag Leaf Collar visible				1128
Boot Swollen				1300-1400
First head of spikelet visible	-1 or -2 (Ventskevich 1958)			1400-1600
Flowering Complete	-1 or -2 (Ventskevich 1958)			1600-1800
Kernel harvest ripe				2100-2480 (Stewart and Dwyer 1987) 5°C
Total GDD				2082-2237 (Spring Barley McMaster, et al.20115.5°C), 1966-2300 (winter barley, McMastr et al.2011 5.5°C) 799-853 for forage grass (5° C: Spring variety)(May, et al. 2007)

5.5 Buckwheat (*Fagopyrum esculentum*)

Although relatively little is known about buckwheat phenology, I briefly consider this crop here, as buckwheat could have played an important role in the economy of ancient southwest China. Relatively little known is about buckwheat domestication, however it is generally accepted that it took place somewhere in southwest China or the Himalayas. This understanding is supported by the distribution of wild members of the genus (Ohnishi 1998). The ability of buckwheat to grow on sandy and poor quality soils, and the relatively short number of growing degree days required by this crop (Table 5.6), mean that it is well adapted to the upland environments which characterize the Himalayas (Edwardson 1995).

5.6 Summary

Table 5.6 summarizes the different requirements in terms of growing degree days, frost tolerance and the cumulative growing degree days required for each crop to achieve maturity. These measures are used to create the maps of growing degree days as described in chapter 4. It is, however, immediately apparent from this table that rice has the highest temperature requirements in cumulative growing degree days and longest growing season of all domesticates and has little to no frost tolerance. It is followed by broomcorn and then by foxtail millet in terms of resistance to cool temperatures. This analysis also reveals that despite its shorter growing season, broomcorn millet has higher cumulative temperature requirements than foxtail millet and requires higher temperatures for germination and successful growth. Both of these species exhibit relatively little tolerance to frost, but can withstand some degree of water stress. While

wheat and barley have longer growing seasons, their cumulative temperature requirements are lower than that of foxtail and broomcorn millet. Both of these crops are sensitive to water stress during key phases of development like flowering and require sufficient water during initial stages of growth

Table 5.6 Summary of the different phenological requirements of crop grown in Southwest China

Crop	**Growing Season Length (days)**	**Frost tolerance**	**Cumulative GDD (10 °C for rice) (5.5 °C for others)**
Rice (*O. japonica*) S China	120	None	2900 +
Rice (*O. japonica)* S China	120-130	None	3000-3300
Rice (*O. japonica*) S China	130 +	None	3300+
Rice (*O. japonica*) N China	130	None	2500
Rice (*O. japonica*) N China	130-150	None	2500-3000
Rice (*O. japonica*) N China	150 +	None	3000 +
Rice (*O. indica*) S China	110-120	None	2400-2600
Rice (*O. indica*) S China	120-130	None	3000-3300
Foxtail millet	60-120	Little. Requires temperatures above 5º C (Brink, 2006). Performs best in temperatures between 16º and 25º C.	2082-2191
Broomcorn millet	45-100	None. Requires temperatures of above 18º C for seedlings to become established (Cardenas, 1983, Kamkar, et al., 2006)	2130-2242 820- 1046 (10°C base : Cardenas 1983)
Winter Wheat	180-250	Seedlings require exposure to temperatures 3º-8º C to initiate flowering. Winter wheat varieties have a high frost tolerance (–20ºC)	1907-2142

Table 5.6 (Continued)			
Spring Wheat	100-130	Spring Wheat varieties do not require exposure to low temperatures and have little to no frost tolerance.	1869-2026
Wheat (Hard Red dwarf variety of breadwheat) Not applicable to archaeological studies	120-170		1538-1665 (0° C)
Spring Barley	60-100	Spring Barley requires a minimum temp of 4.4º C for germination with an optimum temperature above 12º C (Stoskopf, 1985).	2084-2227
Winter Barley	60-100	Seedlings killed at -8º C (Stoskopf, 1985).	1966-2300
Barley (hybrid variety)	60-100		1269-1522 0° C)
Buckwheat	70-90		1200 GDD (5° Degree base)

5.7) Crops and labor

The forth part of my model considers the different labor investment required to grow each kind of crop. Given the literature review carried out above, it again appears that rice is by far the most labor intensive crop to grow. The fact that wheat and barley can easily be affected adversely by drought in key stages of development may mean that some degree of irrigation is necessary under contexts where there is not sufficient rainfall. Foxtail, and in particular broomcorn millet has a much higher tolerance to aridity and can be grown in rainfed and non-irrigated fields, as is the case in China today (Table 5.7).

Table 5.7. Labor requirements for different crops in Southwest China with different types of field structure.

Crop	Field type	Direct Sown	Trans-planted	Irrigation	Labor associated with field construction
Foxtail millet		Yes	No	Not required	No
Broomcorn millet		Yes	No	Not required	No
Wheat		Yes		Yes or rainfed (but needed at key moments)	No
Barley		Yes		Yes or rainfed (but needed at key moments)	No
Upland Rice		yes	No	No (mostly rainfed	No
Paddy Rice	(bunded field system)	Yes	Yes	Yes, can function by diverting stream/river water	Relatively easy to construct and maintain
Paddy Rice	(poldered field system)	Yes	Yes	Yes, uses water from lake floodbank	Requires construction of dyke and field boundaries
Paddy Rice	(sand fields)	Yes	Yes	Yes, uses water from lake floodbank	Requires construction of reeded structure to keep out flood waters
Paddy Rice	(floating fields)	Yes	Yes	Uses water in lake	Requires initial construction of frame, after which little maintenance is required
Paddy Rice	(terraces)	Yes	Yes	Requires substantial investment in irrigation system, to collect or pump water to higher elevations	Requires substantial investment in construction of terraces. Once built requires less work, but still needs maintenance where walls collapse.

Summary

This chapter has summarized the phenological properties of five crops that were grown in southwest China during prehistory: Rice, Foxtail millet, Broomcorn Millet, Wheat and Barley. Of these, this summary concluded that rice has both the highest accumulative GDD requirements and the highest labor input, because lowland varieties required the creation of artificial paddies. Previously, broomcorn and foxtail millet have been hypothesized to be cold adapted crops that are thought to have facilitated the movement of agricultural products across Eurasia, given the fact that they achieve maturity in a short amount of time (Jones, et al. 2011). However, an in-depth look at their phenology found that both of these crops had relatively little tolerance to frost, and their accumulated GDD requirements were higher than that of wheat and in some instances barley. Throughout this review of the literature, one problem became apparent. There is an absence of data on the phenology of landraces of the crops reviewed here. In the future, experimental work on these landraces will give a better estimate of the growing degree days that were required by these crops in the past.

CHAPTER 6

SPREAD OF MILLET AGRICULTURE AND EARLY ADAPTATIONS ON THE PERIPHERIES OF THE SICHUAN BASIN

Discussions of the spread of agriculture to deep South and Southwest China have focused primarily on documenting the spread of rice (Fuller 2012; Fuller and Qin 2009; Zhang 2008; Zhang and Hung 2010; Zhao, et al. 2005). Although the spread of millet agriculture equally if not more critically than rice was accompanied by the movement of languages, peoples and material culture, the manner in which this spread occurred has been relatively neglected. A closer look at the archaeobotanical record shows that both rice and millets played crucial roles in the spread of agriculture into Southwest China. The lack of systematic flotation and the use of practices such as handpicking have favored the recovery of larger grains such as rice or western domesticates. As a result, the role of millets in the spread of agriculture in East and Southeast Asia has been underrated.

As the history of archeological research in highland Southwest China is still in its infancy, early work on understanding the spread of agriculture and peoples into this region has focused on linguistic evidence. Linguistic evidence, primarily focused on rice has been used to hypothesize how early farming spread throughout China, and early studies by Bellwood argue that the spread of rice agriculturalists had the most profound impact on the dispersal of language phyla (Bellwood 2005a; Bellwood and Renfrew 2002).

More recently, the possibility that agriculturalists may have played a role in the spread of agriculture has been explored. In particular, it has been argued that people's inhabiting Northwestern and Southwestern China, particularly Sichuan Province, could have played important roles in the development and spread of the Sino-Tibetan language families. However, several conflicting models exist regarding the timing of this spread and how this spread occurred. Van Driem (1998, 1999, 2002, 2005) believes that the origins of Sino-Tibetan (Tibeto-Burman) are to be found in Sichuan Province, where hunter-gatherer speaking these languages resided as early as 11,500 BC (Van Driem 1999). Based on connections with Burmese language families, he argues that populations moved out of this area into the Himalayas and into Northern India c. 7000 BC, then move into the Indian Himalayas creating the Indian Eastern Neolithic (c. 7000-2000 BC). He then argues that part of these groups spread north to form the Dadiwan culture and Northeast to form the Cishan cultures. From here, Van Driem (1999) argues that one offshoot of the late Majiayao culture migrated south from Northern Sichuan into eastern Tibet, then into Sikkim. Finally, Van Driem (1999) argues that these people began to move into Peninsular Southeast Asia from Sichuan around 1000 BC.

Starosta (2005) on the other hand, believes that one can trace the origins of most languages in East Asia to a Proto-East Asian language that he argues was spoken by millet agriculturalists in the Cishan and Peiligang cultures. He (2005) argues that these people spread East and West. The eastern group became the speakers of Pre-Austronesian, which he identifies with the Longshan culture (discussed in Chapter 7). He argues that these people then spread southward to Majiabang, where they acquired rice agriculture. Starosta (2005) argues that the group that

moved to the west, became the speakers of Sino-Tibetan-Yangzian, which he identifies as the individuals responsible for the spread of the Yangshao culture and its spread around 5500 BC. In a somewhat similar model, Sagart (2008) has argued that c. 6500-5500 BC foxtail, broomcorn millet and rice farmers present in the Yellow River valley spoke PSTAN (Proto-Sino-Tibetan Austronesian). These people then split into two different groups:

a.) A group that moved west and expands throughout the mid and upper Yellow River Valley. Their language evolves into PST (Proto-Sino-Tibetan) that then expands to the south and west.
b.) A group that moved east along the coast and to Taiwan, via the lower Yellow River valley. Eventually develops into AN (Austronesian Languages).

More recently, Fuller (2012; 2010) has argued that the spread of agriculture throughout East Asia took place in a series of 11 thrusts. He correlates 8 of these thrusts with the potential spread of rice agriculture (Fuller 2012). With regards to the spread of millet agriculture Fuller (2012) agrees with Sagart that the speakers of STAN (Sino-Tibetan Austronesian) should be associated with the Yangshao culture and believes that the Yangshao expansion should be tied to the development of Sino-Tibetan.

Archaeological excavations, surveys and analyses carried out over the past twenty years contains important evidence for understanding the movement of people into and out of Southwest China and their relationship to the crops they brought with them.

In this chapter, I discuss the earliest evidence for the spread of agriculture to this region and its implication for the movement of language phyla. I argue that the earliest spread of agriculture to Southwest China involved millet agriculture moving into the highlands of western Sichuan.

Compared to studies of the origins of rice agriculture, the archaeological record for the origins of millet agriculture in Northern China is patchy. Very little systematic flotation has been carried out on early Holocene sites in Northern China and much of our understanding of the transition to agriculture in this region is largely based on chance finds where archaeobotanical remains were visible to the excavators. Although this situation is rapidly changing, much work remains to be done on understanding the transition to agriculture in Northern China. Two main crops are of importance to this transition: these are broomcorn (*Panicum miliaceum*) and foxtail millet (*Setaria italica*). The differing phenology of both broomcorn and foxtail millet played important roles in defining the patterns underlying their spread.

6.1) Origins in the North China Microlithic

Highland southwest China may have been an important area for the movement of hunter-gatherer populations. To date, little evidence from southwest China has become available to document the presence of these peoples, therefore in order to gain an idea of what their lifestyle may have been like, we need to turn to developments in the better studied area of northern China. In order to understand the origins of millet agriculture in Northern China, it is first necessary to review the lifestyle of the hunter-gatherers who occupied this region and who interacted with and began cultivating these plants. Microliths are an important feature of the cultural assemblage associated

with the hunter-gatherers that occupied Northern China during the late Pleistocene and early Holocene (26,000-6000 BC). These microliths are less then 5cm in length, and 1cm in width and were likely used in wooden or bone implements (Lu 1998).

In sites of the terminal Pleistocene, such as Shizitan, grinding slabs accompany these tools, hinting at an intensification of resources. The "North China Microlithic" (Bettinger, et al. 2007) covers a wide area and over 200 sites containing these characteristic microliths have been unearthed in northern China (Lu 1998). The area consisting of the higher elevation foothills of central plains of the Yellow River valley contains some of the earliest evidence for microlithic sites including Xiachuan (26,000-15,000 cal BC), Shizitan (13,800- 8500 cal. BP), Xueguan (14,500 cal BC), and Hutouliang (12,100 cal BC) (Figure 6.1). Little was previously known about the distribution or dates of microliths in the highlands of north-western China, and it was assumed that movement into these areas only occurred later. However, recent small excavations at the sites of Dadiwan (c. 20,000-13,000 cal BP) and Pigeon Mountain (c. 12,700 BP) have demonstrated the early occupation of these regions (Bettinger, Barton, Morgan, et al. 2010). A few finds of microliths have been unearthed in Eastern China (Lu 1998), however, they are not well dated. The distribution of microlithic sites appears to be confined to areas of middle to high altitude (Lu 1998).

Previously, little to no work had been carried out on the subsistence strategies practiced by the occupants of these sites, however, over the past few years an increasing amount of archaeobotanical research has begun to be carried out. Starch grain analysis has been carried out on grinding stones and slabs unearthed from Locality 9 from the site of Shizitan (c. 13,800–8500 cal. BP) (Liu, et al. 2011) (Figure 6.1). The authors uncovered starch that resembled the

following taxa: starch from grass seeds of the Panicoideae and Pooideae subfamilies, acorns (*Quercus* sp.), beans (Phaseoleae tribe) and yams (*Dioscorea* sp.), however the small size of the reference collection used makes these results inconclusive at best.

Although deposits from the site of Donghulin (11,000-9000 BP) were not subjected to systematic flotation, a few seeds of hackberry were hand-picked by excavators from a grave, hinting at their possible consumption (Hao, et al. 2008). Recently, starch grain analysis was performed by the same group on grinding stones unearthed from the early Holocene layers of this site (c. 9200-8700 cal. BP). Although this paper suffers from the same small reference collection as the previous paper, it reveals that these grinding stones may have been used to process acorns (Liu, et al. 2010).

While microbotanical analysis can be very revealing of ancient subsistence patterns, these recent studies remain too focused on only one line of evidence. In order to gain a more complete picture of the subsistence patterns of the inhabitants of these sites, it is necessary to carry out systematic flotation to see if the patterns inferred from these studies hold true.

6.2) A hunter-gatherer legacy in Southwest China?

Prior to the arrival of millet agriculture in Southwest China, little is known about its early inhabitants. It is assumed that hunter-gatherers must have occupied Southwest China during the early Holocene. Current archaeological evidence, has, however unearthed little to no trace of these peoples. Evidence from the site of Ziyang in Eastern Sichuan makes it clear that the mountainous peripheries of the Sichuan Basin have been occupied since Paleolithic times (Ye

1998). However, there is a long gap of time between these Pleistocene occupations and the later Majiayao culture agricultural sites discovered in this region. The discovery of microliths at many sites in the mountainous foothills of Sichuan province suggests this gap in time may be an artifact of excavation practice, and that hunter-gatherers forming part of the North China microlithic interaction sphere could have occupied this region as early as 20,000 BC (Bettinger,Barton and Morgan 2010; Bettinger et al., 2010).

Microliths have been unearthed at many sites to the Northwest and Northeast of the Sichuan Basin. However at all of these sites, microliths are found in association with cultural material such as pottery, adzes, axes and chisels characteristic of later agricultural settlements. Unless they are somehow intrusive, they appear to be dated to much later than those known from the microlithic in Northern China. To the Northeast of the basin, a number of sites have yielded microliths that show similarities to cultural traditions further north in Qinghai or Gansu (Ye 1992; Zhongguo and Sichuan 1991). In 1990, a survey carried out at the site of Zhongzipu by the Chinese Academy of Social Sciences recovered large quantities of microliths from a visible section in the site. While the authors found microliths in all three visible stratigraphic layers of the site, they claim that the stratigraphy was not clear at the time. As a result the authors remained unsure that the pottery and ground stone tools found in prospection dated to the same period as the microliths. Four C-14 dates were been carried out at Zhongzipu, leading the prospectors to suggest the remains date to between 5000-3500 BC (Zhongguo and Sichuan 1991) (Figure 6.1). As these dates were carried out on wood charcoal it is possible that this site may date to even later.

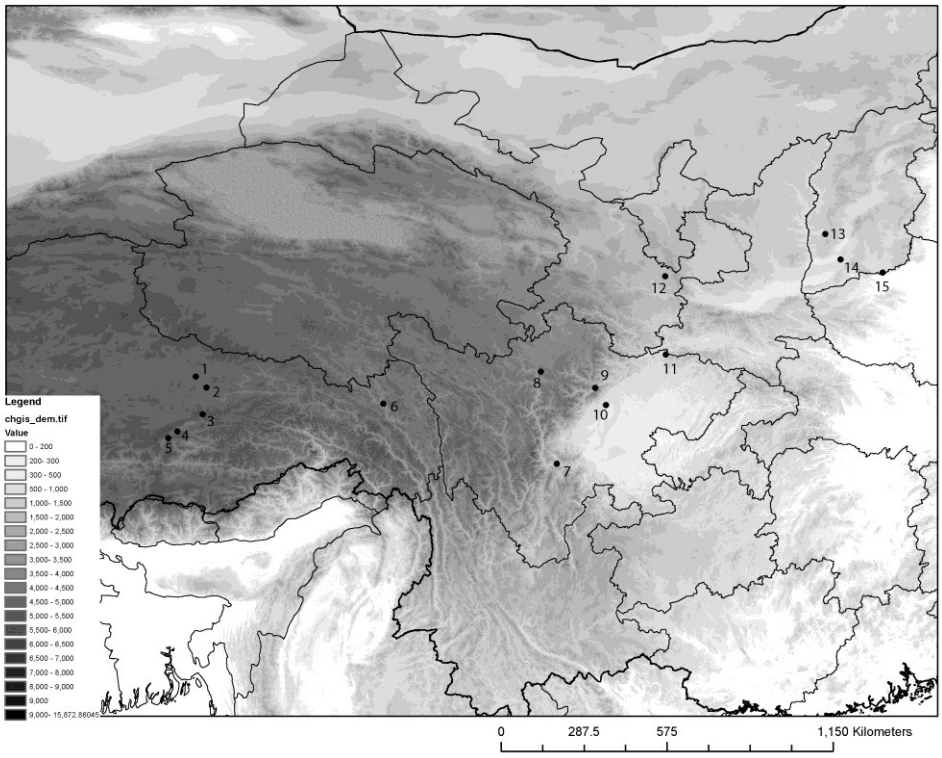

Figure 6.1 Sites containing microliths discussed in the text: 1) Cuona Hu; 2)Buquhe; 3) Jianggepona; 4)Jiaritang; 5)Tuizhunaka; 6) Changdu Karuo; 7) Shizishan and Maiping 8) Haxiu ; 9)Yingpanshan; 10) Guiyuanqiao; 11) Zhongzipu; 12) Dadiwan; 13) Xueguan; 14) Shizitan; 15)Xiachuan

In the northwestern foothills of the Sichuan Basin, microliths have been found in association with the pottery and ground stone tools characteristic of the Majiayao expansion into the area. Interestingly, microliths re-appear in the archaeological record during this period of time after an apparent hiatus in sites of the Miaodigou phase. An area containing cores and unfinished products as well as microliths has been unearthed at the site of Yingpanshan (c.3300 BC) (Chengdu et al. 2002; Chen Jian: Personal Communication 2011).While no direct dates have been placed on the feature from which these tools came, this further complicates the picture surrounding the distribution of microliths throughout time in this region. As no full report on the

excavations of this site has been released, it is difficult to make judgments on the stratigraphic position of these finds. Similar lithic material has also been unearthed in the southern peripheries of the Chengdu Plain at the sites of Shizishan and Maiping (Ma 1992; Zhongguo and Sichuan 1991). Up until recently no microliths were known from sites in the low lying Sichuan Basin, however, excavations at the site of Guiyuanqiao have revealed that microlith producing people also descended onto the plain (Wan Jiao: Personal Communication 2012). At Guiyuanqiao, as with sites in the highlands, these microliths are associated with pottery representative of the Majiayao expansion. Further south in Sichuan, microliths have also been found in large numbers at sites in Dechang County, including Maojiakan, and Wangjiatian (Sichuan Sheng Wenwu Kaogu Yanjiusuo and Liangshan Yizu Zizhiqu Bowuguan 2006, 2007). Microliths have also been found near the Sichuan Yunnan Border (Anke Hein: Personal Communication 2012), namely at the sites of Huili Houzidong, as well as in Yongren county and the Yuanmou Basin (Zhou 1980).

Rock art picturing wild animals suggesting a lifestyle based on hunting is also found in the highlands of Northwestern Yunnan (Jinsha River valley) (Tacon, et al. 2012). This rock art may also point to the possible early occupation of this region. Recent attempts to date this rockart have been made using a combination of Uranium series and radiocarbon dating, and the results suggest that the occupation of this region may go as far as 3700 BC (Tacon, et al. 2012). Further to the West, microliths have also been unearthed at the site of Changdu Karuo on the Tibetan Plateau where they are associated with ground stone tools, pottery and larger flaked tool industries (Xizang Wenguanhui 1985). Large quantities of microliths were also uncovered in a survey of sites in 2003-2004, along the route of the Qinghai-Tibet railroad. These include the sites of Jiaritang, Buquhe, Cuonahu Dongan, Jianggepona and Tuzhuinaka (Xizang Zizhiqu

Wenwuju, et al. 2005). Jiaritang (alt. 4300 m) was the only site out of this group that was excavated. Two distinct cultural layers were superimposed above sterile soil both of which contained pottery, microliths and some ground stone tool. Based on similarities with pottery and stone tools found at the sites of Changdu Karuo and Lhasa Qugong, excavators believe that this site could have dated to 3200-2900 BC, however, the lack of radiocarbon dates makes it possible that it dates to much earlier.

What does the apparent discrepancy in time between sites in the South and sites in the North tell us? The frequent association of microliths with pottery that appears to be linked to the Majiayao expansion into this region, has led many excavators to believe that these microliths form part of a cultural package of expansion into this region. Does this mean that we are looking at the survival of this technology into agricultural periods in Southwest China? If so, did the hunter-gatherers who manufactured these tools continue their use until after they already adopted agriculture? Did agriculturalists moving into these regions re-adopt this technology? Why did microliths disappear from Northern China after the early Holocene and why was their use continued well into the Holocene in Southwest China? These questions clearly have important implications for understanding the history of population movement into this area and for understanding the hunter- gatherer legacy of Southwest China. Recent excavations and systematic sieving at the site of Dadiwan itself (Bettinger, Barton and Morgan 2010), reveal that post-LGM and late Pleistocene/early Holocene hunter-gatherer occupations at the site were characterized by a nanolithic industry where flakes measured less than 9 mm. Such remains would not be found unless all fractions from excavations were sieved using a fine mesh. Future, more systematic and careful research in highland Southwest China may show that this was the case.

In addition to problems of recovery, few of the sites mentioned in Southwest China have been the object of careful excavations or direct dating. It is thus unclear whether the microliths, ceramics and other remains are actually contemporaneous. As later agriculturalists moved into this area, it is possible that their settlements were placed on top of hunter-gatherer encampments. As they built house foundations and dug graves, they could have brought earlier material to the surface. Much more careful and finer excavation of these sites is needed in order to resolve these chronological problems. Doing so may prove that the hunter-gatherer occupation of this region has a much longer history than previously thought.

The lack of evidence for hunter-gatherer occupation in Southwest China, thus far, should not be taken as evidence of the fact these people did not exist. Their presence in less clement climatic conditions in northern China makes it unlikely that the resource rich and diverse area of highland Southwest China was entirely uninhabited until the spread of agriculture. It is, however, likely that these people were highly mobile and their ephemeral occupations have not been picked up on by current archaeological work in the region. Given the very small number of excavated sites in this area in general, this is not altogether unsurprising. The potential presence of an earlier hunter-gatherer presence in Southwest China lends some support to Van Driem's (1999) hypothesis that hunter-gatherers living in Sichuan may have contributed to the early spread of languages and culture across East Asia. The review in chapter 4 of the vegetation of the Yunnan-Guizhou plateau and western Sichuan suggests that a large number of edible wild fruits (peach, jujube, kiwi, nuts (pine nut, walnut, acorn) and tubers (*Potentilla* etc) were present throughout southwest China and could have successfully sustained populations of foragers in this region.

Future work on modeling the density of these resources is necessary to understand how large of a population these resources could have sustained.

Given the current nature of the evidence, it does, however, appear that the hunter-gatherers inhabiting the highlands of northern and southern China were likely highly mobile and were engaged in long distance movement and exchange across these highland territories. They were likely too mobile and too few to leave more than very sparse records. Future research and more careful excavations are needed to test this hypothesis.

6.3) Spread of Millet Agriculture to the Sichuan Highlands

Very little is known about the process that led to the domestication of broomcorn and foxtail millet and so far no clear morphological evidence for a trajectory to domestication has been elucidated. In addition, no single site contains evidence of a clear transition from foraging to farming and deposits containing already domesticated millets are found directly on top of hunter-gatherer sites. As a result, we know little about the timing and process underlying their domestication. A clear criterion for identifying morphological domestication in these millets is necessary to understand the mechanisms and timing by which these two crops began to be cultivated. More systematic excavations at early sites in general are also needed. Both of these crops appear relatively suddenly in Northern China in what seems to be a fully domesticated state (see discussion in Chapter 5).

In addition to being plagued by a lack of archaeobotanical evidence, the wide geographic zone implicated in origins of millet cultivation further complicates the picture. Sites implicated in

early millet cultivation are located in the foothills of Western China, the Yellow River valley, the eastern province of Shandong and the North-Eastern Plains. While many accept that millet agriculture must have moved into Southwest China from the North, the mechanism by which this spread occurred is far from clear. For instance, if one is to accept that hunter-gatherers were present throughout the highlands of southwest China, then why should millets have first been cultivated in northwestern China? One major difference that could explain this fact, may have to do with the fact that highland southwest China is one of the hotspots for biodiversity. Faced with a rich array of resouces, hunter-gatherer's in this region may have had little motivation to uptake agriculture. On the other hand, in northern China, fewer resources and sharp climatic changes at the beginning of the Holocene may have provided the push that lead to early agriculture (Bettinger, Barton and Morgan 2010).

6.3.1) The Yangshao Expansion

The expansion of remains related to the late Yangshao culture into the highlands surrounding the Sichuan Basin is at the heart of the expansion of the earliest agriculture into this region. The earliest expressions of the Yangshao culture (4800-4200 BC) first appear in the Central Plains, at settlements such as Banpo and Jiangzhai (Xi'an Banpo Bowuguan, et al. 1988). During the Miaodigou phase (c. 4000-3500 BC), the culture begins to expand and extends its influence to Gansu and Eastern Henan, where painted vessels with geometric designs begin to form an important part of the archaeological assemblage. This period of time also correspond to a phase of warmer and milder climate (see chapter 4). The Majiayao phase (c. 3500-2500 BC) is characterized by a westward thrust into the provinces of Qinghai and Gansu (Yan 1989) and by the production of high quality painted ceramic vessels.

Extensive work carried out by the Chengdu City Institute of Archaeology over the last decade shows that this culture expanded not only west but also southward into the Sichuan highlands as early as the Miaodigou period. Evidence for Miaodigou period occupation of this region comes from the sites of Boxi and Jiangduichen in Maoxian County. A fragment of a painted bowl found in the lower levels of the site of Boxi shows strong similarities to those known from Miaodigou phase sites in Northern China, leading the excavators to believe that the occupation of this site could date to as early as 4000 BC. To date, remains of this phase have been unearthed at only four sites: that of Boxi 波西 and Yingpanshan 营盘山 in Maoxian County, Jiangduichen 姜维城 in Wenchuan County, and Gongnaruo 官纳若 in Heishui County (Chen 2007). In addition to the rare finds of painted pottery, pottery of this earlier phase is characterized by fine paste that is often polished to a high shine. Ground stone tools are also common in sites of this period.

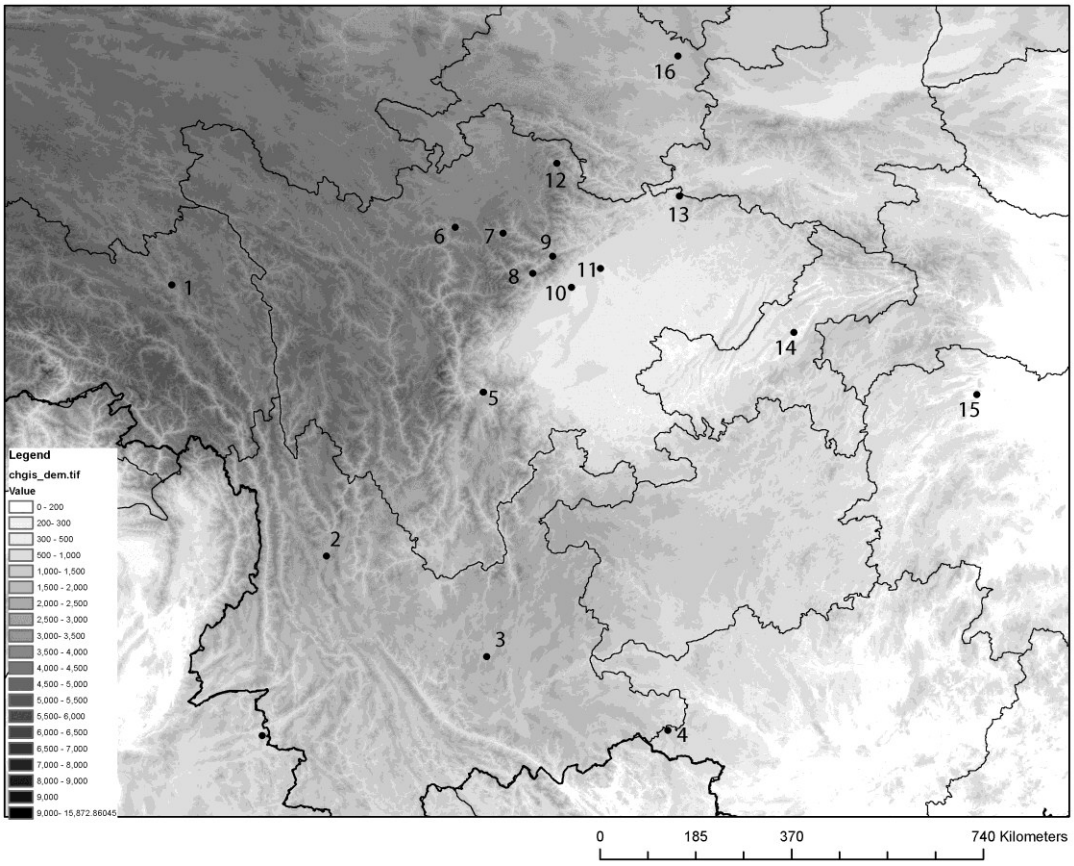

Figure 6.2 Sites with evidence for millet agriculture in Southwest China discussed in the text. 1) Changdu Karuo 2) Haimenkou 3) Shizhaishan 4) Gantuoyan 5) Shizishan/Maiping 6) Haxiu, 7) Gongnaruo, 8) Jiangduichen; 9) Yingpanshan; 10) Guiyuanqiao; 11) Bianduishan; 12) Ashaonao; 13) Zhongzipu; 14) Zhongba; 15) Chengtoushan; 16) Dadiwan

With the transition to the Majiayao phase (c. 3500 BC), sites become widely spread across western Sichuan. In this region, two radiocarbon dates place this phase at approximately 3300-2600 cal BC (Aba et al. 2008). Sites of this period show clear cultural affinities with the Majiayao heartland, particularly the finds from period 4 layers at Dadiwan. This is clearest in the painted pottery excavated from these sites. Painted pottery has been unearthed from Yingpanshan (Chengdu Shi Wenwu Kaogu Yanjiusuo, et al. 2002), Anxiang, Longxizhai,

Jianshanzhai (Hong, et al. 2011), Boxi and Jiangduichen in Maoxian County (Sichuan Sheng Kaogu Yanjiusuo 2006), Changpingcun in Songpan and Ashaonao in Jiuzhaigou, Konglongcun, Baiyu, Hanleyi, Yenongqiujing and Haxiu in Ma'erkang (Aba Zangzu Qiangzu Zizhizhou Wenguansuo, et al. 2008) and Dazasi and Banmajian in Ruo'er County near the Gansu border (Sun and Deng 2006). Finally, near the southern borders of the plain, painted pottery has been unearthed at Shizishan in Hanyuan County (Ma 1992). Unlike sites in the Majiayao heartland where this type of painted pottery constitutes over 20% of the assemblage, the proportion in Western Sichuan are much lower with roughly 2-3%. Recent analysis of this pottery has shown that it was traded into Western Sichuan from the Majiayao heartland in Gansu and Qinghai (Cui, et al. 2011; Hong, et al. 2011). It is interesting to note that the expansion of the Majiayao culture into highland western Sichuan also corresponds to a period of increased temperatures and higher rainfall.

The Yingpanshan site was the object of several series of excavations by the Chengdu City Institute of Archeology (Chen 2007; Chengdu Shi Wenwu Kaogu Yanjiusuo, et al. 2002). Two main periods of occupation were observed: the Early Majiayao phase (3500-3300 BC) and the Shilingxia phase of the Majiayao culture (3500-2600 BC). Five radiocarbon samples date the site to c. 3300-2600 BC. Excavations at the site revealed several different activity areas. In a residential area, large numbers of postholes from buildings were found along with ashpits for discarding waste and possible storage pits. Interestingly, a number of human sacrifices were found in this area of the site. A number of kilns were unearthed in anothr area of the site that appears to have been reserved for pottery manufacture. In another part of the site, large amounts of microliths and microlith cores were unearthed, leading the excavators to believe that this area

of the site may have served as a zone of tool manufacture. Publication of the full excavation report from this site should allow us to determine if these microliths date to earlier periods or are indeed associated with the Majiayao cultural phases.

6.3.2) Archaeobotany of Yingpanshan and Haxiu

Archaeobotanical analysis of two sites relating to the Majiayao phase is currently in progress at the Chinese Academy of Social Sciences (Zhao Personal Communication: 2008). Remains from the site of Haxiu (c.3300-2700 BC) show that subsistence was based on both broomcorn (*Panicum miliaceum*) and foxtail (*Setaria italica*) millet (Aba et al. 2008; Aba et al. 2007; Zhao Personal Communication 2008). Other additions to the diet at this site include Apricot (*Prunus armeniaca*), Oats (*Avena* sp.) and possibly Sichuan Peppercorn (*Zanthoxylum simulans*). However a detailed report has not yet been published.

An archaeobotanical analysis was carried out at the site of Yingpanshan in 2006 by Zhao Zhijun, and a preliminary report of this analysis was published in 2011 (Zhao and Chen 2011). A total of 9 small samples were retrieved from ashpits and these samples were processed using bucket flotation. No information on the size of the mesh or laboratory methods were described, however, given my knowledge of the laboratory we can assume that they were sorted down to the 1mm fraction. The results from the archaeobotanical analysis at Yingpanshan show that the inhabitants of the site were primarily reliant on both broomcorn and foxtail millet. Together these form over 50% of the total seed assemblage (Chengdu Shi Wenwu Kaogu Yanjiusuo, et al. 2002; Zhao and Chen 2011). Both crops were found in roughly equal proportions.

The proportion of *Chenopodium* found at the site is high, constituting over 30% of the assemblage. *Chenopodium* is a common weed in many dryland agricultural fields in China and across the world today (Wang 1990). *Chenopodium* also rapidly occupies disturbed land (Holzner and Numata 1982), and it is possible that it entered the assemblage either as a weed of millet agricultural fields or was discarded when the area around the site was cleared. Unlike other weedy grasses, *Chenopodium* is a member of a different family and is very difference in appearance to the millets, and is easily distinguishable. In order to have entered the assemblage as a weed of dryfield agriculture, farmers would have had to cut stalks of foxtail millet near the base using a sickle.

Zhao and Chen (2011) raise the possibility that the *Chenopodium* may have been cultivated or gathered as a food source at Yingpanshan and other sites in Southwest China. Large quantities of *Chenopodium* unearthed at the site of Haimenkou in Yunnan province have lead the authors to argue that this plant may have been gathered and consumed by the inhabitants of the site (Xue 2010). This is supported by the fact that *Chenopodium* was used as a food source in later times. In particular, *Chenopodium* has been found in jars in Han dynasty tombs where it was clearly being consumed (Yang and Liu 2009). The leaves of the plant are also edible.

In the New World, *Chenopodium* has a long history of use. In North America, it is thought that a wild type of *Chenopodium* (*C. berliandieri*) was cultivated by Native Americans as early as 2000 BC (Asch and Asch 1977). As *Chenopodium* is also a common weed, the documentation of morphological domestication has been central to proving that it was used by humans. In North

America, a reduction in the thickness of the testa shows that this species was under domesticatory pressure by 500 BC (Fritz 1990; Smith and Cowan 1987; Wilson 1981). In the Andes, less is known about *Chenopodium* use in prehistory because the presence of different species with different testa thickness has complicated identification of domestication (Bruno 2008). There is some consensus that domestication may have taken place somewhere between 3000-1500 BC (Bruno and Whitehead 2003; Nordstrom 1990). Many Andean specialists believe that *Chenopodium* usage and eventual domestication arose from humans beginning to exploit wild populations, which colonized the disturbed soil in areas surrounding human habitats (Kuznar 1993; Pearsall 1980, 1992). Given the large quantities of *Chenopodium* found at Yingpanshan it is possible, therefore, that this weed may have been harvested and consumed by the inhabitants of the site.

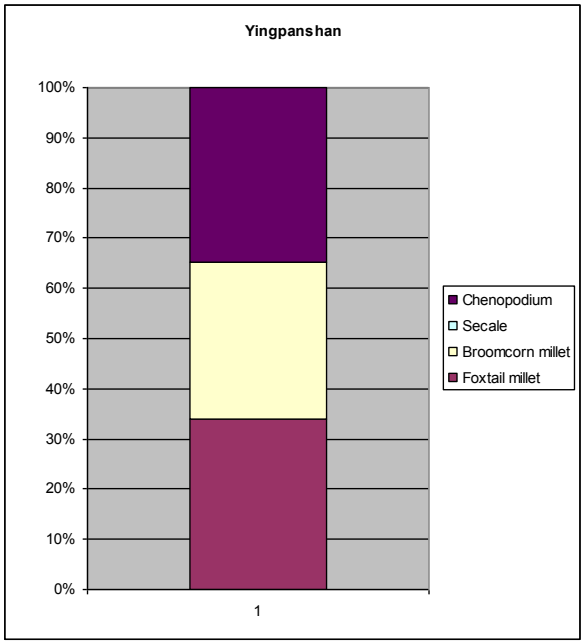

Figure 6.3 Proportion of main cereal crops at Yingpanshan (after data presented in Zhao and Chen 2011)

Two other non-grain crops were present in the assemblage at Yingpanshan: wild soybeans and beefsteak plant seeds. Despite its huge economic importance, the history of soybean domestication is poorly documented. Genetic studies suggest that a genetic bottleneck occurred during the domestication of the soybean (Hyten, et al. 2006), however, these genetic studies have not been able to clarify when use of the soybean began. The earliest archaeological evidence for the soybean comes from sites of the Peiligang culture. A single soybean has been found at Bancun (Kong, et al. 1999), and large quantities of soybean were unearthed at Jiahu, where they are estimated to have been an important resource (Zhao and Zhang 2009). Soybean has also been found in late Yangshao sites in the Yiluo River valley dating to roughly 3700-3000 BC (Lee, et al. 2011; Liu, et al. 2012). Compared to Japan and Korea, extremely small soybeans are present during the Chinese Neolithic (between 2-4 mm in length and width) (Lee, et al. 2011). Between 3000-2000 BC, large quantities of soybean have been found at Longshan period sites. In Korea, soybean has been unearthed at sites of the Nam river valley and radiocarbon dated to 2840–2650 cal BC. In Japan, soybeans appear in the archaeological record during the middle and late Jomon (c. 3000-1000 BC) (Kudo and Sasaki 2010; Obata 2011; Obata and Manabe 2011; Sakamoto, et al. 2006; Sasaki, et al. 2007). Zhao (Zhao 2010c; Zhao and Fang 2007) has argued that domesticated soybeans are present at the Longshan site of Wangchenggang in Henan Province on the basis of their large size (c. 3000-1000 BC). Between 2000-1000 BC, or during the Erlitou and Shang periods, the size of soybeans appears to increase Lee et al. (2011) note a clear bimodality in the assemblage indicating that some kind of selection for size had occurred. They argue, however, that cultivation of soybeans in China very likely precedes any selection for increase in size. Lee et al. (2011) further argue that genetic evidence supports multiple origins of

soybean domestication (Abe, et al. 2003; Gai, et al. 2000; Xu, et al. 2002). The implications of this study are important as it suggests that soybeans were not only domesticated multiple times, but also that different kinds of selection processes lead to their cultivation.

Up until recently, there was no evidence for soybean cultivation in Southern China, making the finds at Yingpanshan important for understanding the history of the use of this crop. At Yingpanshan, as in much of Neolithic China, soybeans are small, barely reaching 2mm in size (Zhao and Chen 2011). Their early date and large numbers may imply that southwest China could have also played an important role in soybean domestication.

In terms of gathered fruits recovered at the site, large amounts of peach shell (*Prunus persica)* were recovered from these samples. Other gathered fruits and nuts include Chinese plum (*Prunus mume*), and Chinese apricot (*Prunus armeniaca*), walnut (*Juglans* sp.) and a wild species of grape (*Vitis* sp.). A large number of seeds of common sea-buckthorn (*Hippophae rhamnoides*) were also found. Common sea-buckthorn is a plant which is native to much of the old world and carries edible fruits with a high vitamin C content. Currently China is the largest producer of common sea-buckthorn, which is used medicinally, in beverages, consumed as a fruit, and used for remediation of poor agricultural lands (T, Li 1999; Li and Schroeder 1996; Xu 1994). Common sea-buckthorn has a mutualistic relationship with a species of bacterium (*Frankia* sp.), which fixes atmospheric nitrogen to the soil, providing the plant with an adequate supply of nitrogen allowing it to be grown in poor soils (Small, et al. 2002). Yingpanshan contains the first archaeological evidence of the exploitation of this crop. It is clear that the inhabitants of the site seasonally incorporated large amounts of gathered foods and fruits into their diet. Seeds from

Chinese sumac (*Rhus chinensis*) were also uncovered at the site. Today these are used to produce galls that are used medicinally (Djakpo and Yao 2010).

The movement of millet agriculture into this region is also accompanied by pig husbandry, and the bones of domestic pigs have been uncovered at nearly all Majiayao sites in Western Sichuan (He et al. 2009). Based on an analysis of MNI, He et al. (2009) calculate that pig formed the most important contribution to the diet. In addition to pig, subsistence appears to have relied heavily on hunting. A number of different wild birds were unearthed at Yingpanshan, along with large quantities of hunted mammals including spotted deer (*Cervus nippon),* sambar deer (*Cervus unicolor),* Reeve's muntjac *(Muntiacus reevesi),* long-tailed goral (*Naemorhedus caudatus*)*,* hare (*Lepus* sp.), bamboo rat (*Rhizomys* sp.*),* hog badger (*Arctonyx collaris*)*,* asian black bear (*Selenarctos thibetanus),* the Tibetan macaque (*Macaca thibetana)* and presumably domestic cattle (*Bos taurus)*.

Despite the evidence for domestic cattle, the inhabitants of the site do not appear to have practiced dung burning. No weight was given for seed remains so we were not able to calculate a seed to wood charcoal ratio for the site, however, Zhao and Chen (2011) note that a very high proportion of wood charcoal was found at the site, indicating that the inhabitants may not have practiced dung burning but rather used trees as fuel. Although an analysis of wood charcoal type was not carried out, the presence of Chinese yew seeds (*Taxus chinensis*) at the site makes it possible that the inhabitants of the site burnt shrubby species. No remains of goat or sheep were found at the site indicating that a pastoral lifecycle had not yet made its way to Western Sichuan (He, et al. 2009).

6.4) Spread of agriculture to the Tibetan plateau: evidence from the site of Changdu Karuo

The arrival of millet agriculture in foothills of western Sichuan appears to have led to the rapid spread of these agricultural products into areas of higher altitude such as the Tibetan plateau. Important evidence for understanding how agriculture moved into these challenging and higher altitude environments comes from the site of Karuo (ca. 3950- 2050 cal. BC), which is located near Changdu (Chamdo). This site is situated at an altitude of 3100 meters above sea level and shows important connections to sites in western Sichuan in several regards.

The site of Karuo in Changdu was excavated in 1978 and 1979 (Xizang Wenguanhui 1985). The excavators divide the site into three occupation phases. All three phases have semi-subterranean house structures and large quantities of pottery and stone tools. A particularly interesting find is that of an incised and painted double bellied vessel that bears some resemblance to Majiayao culture vessels in western Sichuan. A few other painted vessels bearing some resemblance to Majiayao vessels were also unearthed from the site. Ground axes and adzes as well as ground stone knives (or sickles) also show similarities to cultural material unearthed in the Minjiang river valley of Western Sichuan. In 2002, an additional series of small scale excavations were carried out at the site by Sichuan University and the TAR Cultural Relics Bureau. A total of three houses and 16 ash pits were unearthed and 6 charcoal samples were submitted for radiocarbon analysis (Li 2007; Zhongguo Shehui Kexueyuan Kaoguyanjiusuo 1991). The features are from the last period of occupation of the site (ca. 2000 BC).

During the first season of excavation, a total of 42 radiocarbon dates were taken from wood charcoal (Table 6.1). I carried out an additional 8 dates on seeds found in contexts dating to the later phase. These dates overlapped neatly with dates carried out on wood charcoal and appeared if anything to date to the earlier part of this phase. Despite the problems common with dating wood charcoal, it appears, that the charcoal dates are reliable and the features dating to early occupation of the site largely pre-date 2500 cal. BC, with the earliest dates reaching approximately 3500 cal. BC. Samples dating to the later occupation of the site appear to post-date 2700 cal. BC.

The fact that these dates were carried out on wood charcoal may mean that the start of occupation at the site was considerably later. There are several reasons for this: 1.) the charcoal may contain clay that contained old carbon, 2.) charcoal may have been derived from the inner rings of trees leading to an earlier date, or 3.) or that wood resources were reused by the inhabitants of the site. This is not entirely unexpected for a site on the Plateau where wood is a limited resource. In addition, considerable perturbation seems to have occurred at the site, leading to the movement of earlier material into later occupations. The occupation of the site appears to have been terminated around 2000 cal BC if we consider the later dates derived from earlier features showing up in this phase to be anomalous as they appear to be.

Table 6.1 Radiocarbon dates carried out at sites on the Tibetan Plateau discussed in the text.

Site Name	Stratigraphic Information	Phase	Lab. No.	Date (C14 years)	+ -	Plant Part
Karuo	**F18-170cm**	Early	ZK0816	5120	300	Wood charcoal
Karuo	**T62(3)F17:84**	Early	ZK0815	4810	100	Wood charcoal
Karuo	**T102(3) F18**	Early	BK79072	4550	100	Wood charcoal
Karuo	**T41F9(3)**西壁	Early	BK79069	4540	80	Wood charcoal
Karuo	**T102(3) F19**	Early	BK79071	4490	90	Wood charcoal
Karuo	**T62(3)F17**	Early	WB79-58	4460	85	Wood charcoal
Karuo	**F7:24** 陶罐下	Early	ZK0810	4420	110	Wood charcoal
Karuo	**T1(2)-30cm**	Late	ZK0617	4390	100	Wood charcoal
Karuo	**T103(4)F31**	Early	BK79073	4380	100	Wood charcoal
Karuo	**T102(3)F19**	Early	ZK0817	4300	90	Wood charcoal
Karuo	**(3)F29** 西北角柱洞	Early	BK79077	4280	80	Wood charcoal
Karuo	**T61(3)F14** 烧土下	Early	ZK0813	4280	100	Wood charcoal
Karuo	**F3(3)**	Early	ZK0637	4190	90	Wood charcoal
Karuo	**F3(3)**	Early	BK78044	4180	120	Wood charcoal
Karuo	**T42(4)F8** 低	Early	BK79074	4160	80	Wood charcoal
Karuo	**T4(3) F9**	Early	ZK0812	4160	100	Wood charcoal
Karuo	**T56(3) F20** 柱洞	Early	WB79-51	4120	140	Wood charcoal
Karuo	**02XCK T7 H2**	Late	BA111228	4115	25	Foxtail Millet
Karuo	**T4,T14F12(2)(3)**	Early	BK79070	4110	100	Wood charcoal
Karuo	**T22(2)-133 cm**	Early	ZK0620	4110	80	Wood charcoal
Karuo	**T42(4)F8** 东壁	Early	ZK0811	4060	100	Wood charcoal
Karuo	**T102(3)F19** 柱洞	Early	WB79-52	4030	75	Wood charcoal
Karuo	**F15** 柱洞内	Early	ZK0814	4030	100	Wood charcoal
Karuo	**F4(6)**	Early	BK78046	4000	85	Wood charcoal
Karuo	**02XCK T7 H1**	Late	BA111229	3995	25	Foxtail Millet
Karuo	**T7 东壁(3)H4**	Late	Beta325960	3980	40	Broomcorn Millet
Karuo	**T24,T13, T23F5**	Late	ZK0636	3980	90	Wood charcoal
Karuo	**T7 H1**	Late	BA111230	3965	25	Undet Fragments
Karuo	**T12(2)**	Late	ZK0619	3950	95	Wood charcoal
Karuo	**T7 东壁 3 下 H4**	Late	BA111227	3945	20	Undet Fragments
Karuo	**F5(4)**	Late	BK78045	3940	80	Wood charcoal

Table 6.1 (Continued)						
Karuo	**T7 东壁 3 下 H4**	Late	BA111226	3910	25	Foxtail Millet
Karuo	**T62(3)F17**	Late	BK79068	3910	90	Wood charcoal
Karuo	**F4 柱内**	Late	WB78-34	3910	130	Wood charcoal
Karuo	**T7 F1**	Late	BA111231	3895	25	Undet Seed
Karuo	**T102(3)**	Late	WB79-54	3870	70	Wood charcoal
Karuo	**T103(4)F31**	Late	ZK0820	3870	100	Wood charcoal
Karuo	**F5**	Late	WB78-35	3840	80	Wood charcoal
Karuo	**F1**	Late	WB78-37	3820	90	Wood charcoal
Karuo	**F30(2)**	Late	ZK0819	3820	80	Wood charcoal
Karuo	**F22(2)**	Early	ZK0818	3790	80	Wood charcoal
Karuo	**F22-29**	Early	WB80-63	3760	95	Wood charcoal
Karuo	**T13(2)-150 cm**	Late	ZK0618	3760	170	Wood charcoal
Karuo	**T42(4)F8** 低	Early	WB79-57	3740	70	Wood charcoal
Karuo	**T59(2)F10**	Early	WB79-59	3610	165	Wood charcoal
Karuo	**F3**	Early	WB78-36	3600	95	Wood charcoal
Karuo	**T4(3)F9** 东北角木柱	Early	WB79-55	3580	95	Wood charcoal
Karuo	**T4,T14F12(2)(3)**	Late	WB79-53	3540	105	Wood charcoal
Karuo	**02XCKT7K1**	Late	BK200264	4105	70	Wood charcoal
Karuo	**02XCKT7F1**	Late	BK200265	4070	70	Wood charcoal
Karuo	**02XCKT3F1**	Late	BK200266	3890	70	Wood charcoal
Karuo	**02XCKT7H2**	Late	BK200267	3975	70	Wood charcoal
Karuo	**02XCKT7H1**	Late	BK200268	3848	70	Wood charcoal
Karuo	**02XCKT1 (4)**	Late	BK200269	4716	80	Wood charcoal

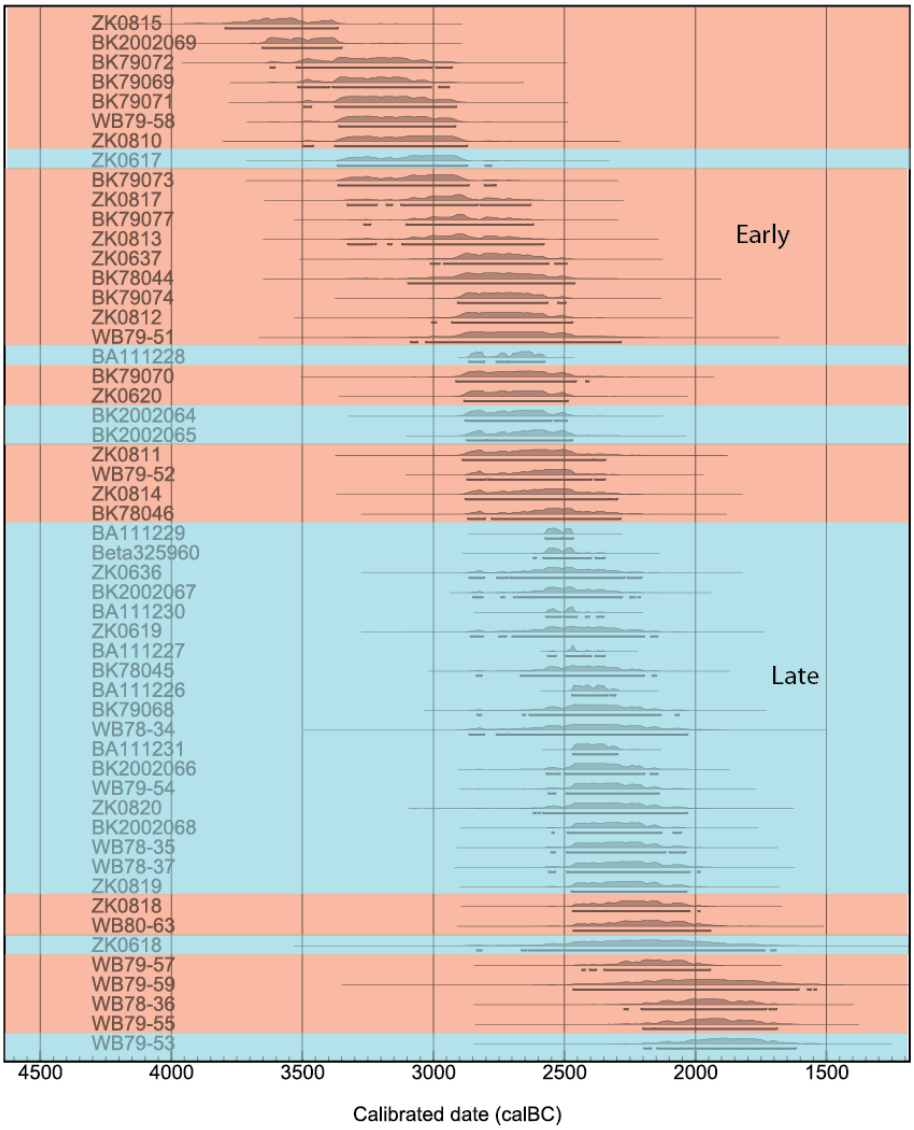

Figure 6.4 Calibrated Radiocarbon Dates for the three phases represented at Karuo showing the two-sigma probability intercepts with the calibration curve (from IntCal 2009). Dates are in order of uncalibrated radiocarbon determination (see Table 6.1 for uncalibrated dates).

A zooarchaeological analysis of remains unearthed in the first season of excavation identified the presence of domesticated pig and an unidentified species of bovid (represented by two teeth).

Despite the presence of these domesticated animals, subsistence appears to have focused primarily on hunting deer. No MNI counts are presented in the report, however, numbers of deer elements (particularly Chinese water deer (*Hydropotes inermis*) seem to dominate the assemblage (Xizang Wenguanhui 1985). A number of other species are present, including red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), goral (*Naemorhedus goral*), serows (*Capricornus sp.)*, Tibetan gazelle (*Procarpa picticaudata*), Chinese water deer (*Hydropotes inermis*), Alpine Musk deer (*Moschus sifanicus*), Tibetan Antelope (*Pantholops hodgsonii*), Baral or Himalayan Blue Sheep, Muntjac etc. In addition, wooly hare (*Lepus ojostolus*), Himalayan Marmot (*Marmota himalayana*), White eared pheasant (*Crossoptilon crossoptilion*), and a number of species of macaques as well as dog and one species of fish in the genus *Schizopygopsis* (Aldenderfer and Zhang 2004; Li 2007; Xizang Wenguanhui 1985). Samples collected in the 2002 excavations show a similar array of animals, however, here again no MNI counts are presented (Li 2007).

Archaeobotanical samples were collected during the first two seasons of excavation from a pit feature located near the eastern wall of the semi-subterannean house number 8 (79CHKF8:58), which belonged to the later part of the early period of the site (c.3000-2500 BC). It is clear that this square living structure was destroyed by fire as a number of burnt postholes were found in situ. In addition, a scatter of objects across the surface of the house appeared to be left in situ. These objects include a number of ground stone adzes and axes, bone tools, as well as microliths and microlithic cores, which show some similarities to those unearthed at sites such as Yingpanshan and Huili Houzidong. The archaeobotanical samples were analyzed by the Botany department of the Chinese Academy of Sciences and were reported as containing only *Setaria*

italica (Xizang Wenguanhui 1985:167-169). Six samples for flotation were taken during the 2002 excavations in units from a series of ashpits (H1, H2, H4, K1), House 1 from unit 7, and L3. The analysis of one sample from a radiocarbon dated unit (Ashpit H4) was carried out by Fu Daxiong and he reported finding more *Setaria italica* (Li 2007).

During the winter of 2010, I re-examined the samples extracted from the 2002 excavations at Karuo. As these samples were not taken under the supervision of an archaeobotanist, all samples from Karuo were small and weighed less than 1 L in volume. It is thus unlikely that these samples are representative of the full spectrum of plant foods consumed by some of the earliest agricultural inhabitants of the Tibetan Plateau. Despite the small number of seeds, these samples nevertheless pointed to several important facts about early subsistence on the plateau. The results of this analysis are presented in Appendix C. Contrary to previous analyses, the results revealed that both broomcorn and foxtail millet were exploited by the inhabitants. Both crops were subjected to direct dating and dates were consistent with the occupation of the site (Table 6.1).

The discovery of both millets at Karuo suggests that an agricultural system closely analogous to that of Qinghai/Gansu and western Sichuan was practiced. Although our sample size was small, it was also apparent that foxtail millet was more ubiquitous (83 percent of the samples) and abundant (total count = 66 [seeds and fragments]) than broomcorn millet (ubiquity = 50 percent and total count = 11 grains).

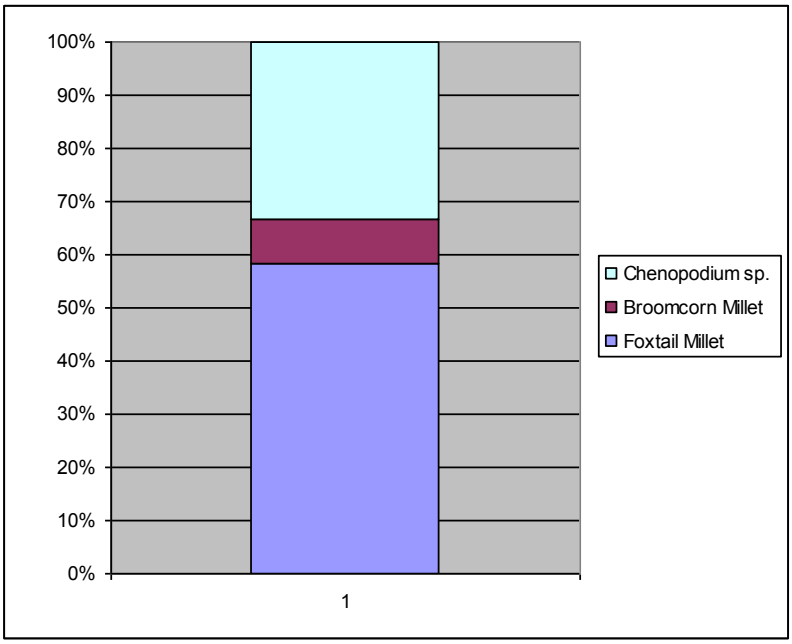

Figure 6.5 The proportion of broomcorn millet, foxtail millet and *Chenopodium* at Karuo based on total counts.

This analysis also revealed the presence of wild fruits, including *Fragaria/Potentilla* and *Rubus* sp., which may have been consumed by the inhabitants of the site. All specimens recovered were carbonized.

6.5 The Spread of Millet Agriculture to Highland Eastern Sichuan: Evidence from the site of Zhongba

Flotation has only been carried out at one early site in the Eastern part of the Sichuan Basin: Zhongba. Samples from Zhongba range in date from 2500-200 BC (Zhao and Flad ND). Although relatively late, these samples contain important evidence for millet exploitation in the

highlands surrounding the Sichuan Basin. Despite signs of some cultural connections with rice producing sites of the Middle Yangzi, flotation at Zhongba shows a clear reliance on broomcorn and foxtail millet and not rice.

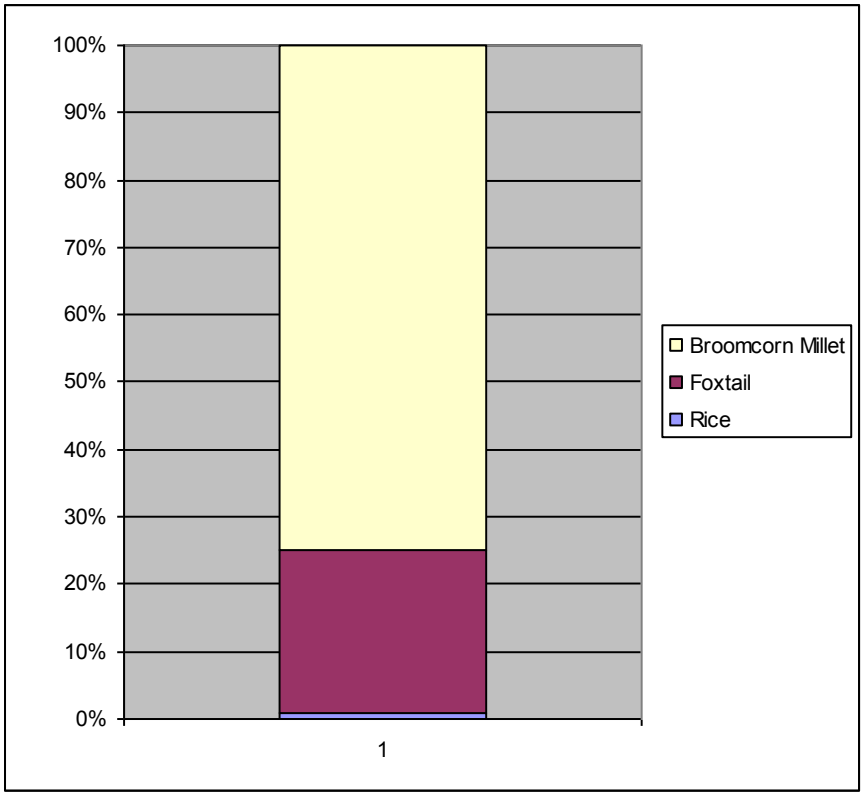

Figure 6.6 The proportion of broomcorn millet, foxtail millet and rice at Zhongba based on total counts

Only one fragmentary grain of rice is present in the samples from Phase 1 (2500-1750 BC) and none were found in the two poorly preserved samples from Phase 2 (1750-1100 BC). Only in Phase III (1100-200 BC) does the ubiquity of rice increase slightly. The weed assemblage that was recovered at Zhongba yields some interesting information about the nature of agriculture that was practiced at the site. Weed flora was primarily composed of dryland weeds, although

these are very few in number. The low number of weed seeds found at Zhongba may be due to problems with the recovery system used by the authors (Zhao and Flad ND). During flotation a cheesecloth mesh of unspecified size was used, hence it is possible that many smaller seeds were lost during this process. In addition, although the laboratory recovery methods were not discussed in the report, the paleoethnobotany lab at Chinese Academy of Social Sciences generally does not sort seeds smaller then 1 mm, which biases results to include only larger seeded domesticates (Jiang Ming: Personal Communication 2011). The lack of wetland weeds associated with paddy agriculture further suggests that the few finds of rice may not have been grown locally. Based on data from only one site, it is difficult to say whether or not this pattern of subsistence is reflective of Eastern Sichuan generally or a small geographical locale. Zhao and Flad (ND) have suggested that this may be due to local conditions surrounding the site. It is indeed possible that the more vertical topography of this area and very saline soils may have presented a challenge for creating the water management systems associated with rice paddy agriculture, thus prompting the use of dryland crops.

6.6) Spread of millet agriculture to the Chengdu Plain: Evidence from the site of Guiyuanqiao

The site of Guiyuanqiao in Shifang County was discovered in April of 2008, during a prospection mission carried out by the Sichuan Provincial Institute of Archaeology at the site of a cigarette factory. Excavations were carried out at the site from May to August of 2009 and layers dating to the Neolithic, the Western Zhou, Han Dynasty and Song dynasty were unearthed. The site covers roughly 30,000 square meters and total of roughly 3000 square meters were

excavated. The most important discovery at Guiyuanqiao was layers that contain the earliest evidence of habitation of the Chengdu Plain. Prior to the discovery of Guiyuanqiao, it was believed that the earliest site in the Chengdu Plain was the site of Baodun in Xinjin County (c. 2700-2000 BC). The evidence from Guiyuanqiao demonstrates that the inhabitants of the Yingpanshan culture also exploited lowland environments. Remains relating to the Neolithic occupation of the site were mostly distributed in the south and western areas of the site. The southern area was the best preserved, with early deposits measuring over 0.3 meters in depth. Two areas of burnt earth were unearthed along with two postholes, one stove area, 27 ash pits and one grave.

Remains relating to the Neolithic could be divided into two main phases. The first phase constituted the remains in level 6 and directly below and above. Features unearthed in this layer include two areas of burnt earth, two postholes, and 8 ash pits. An area of burnt earth covered over 40 $m^{2,}$ however, as no associated postholes were found. The excavators do not believe it constitutes the outlines of a house. A large ashpit (roughly 4m in diameter) was found inside this feature and it contained large amounts of grains, ash and pottery fragments along with a few reconstructible vessels. Vessels from this period were characterized by having sandy inclusions and were fired at a low temperature, however, there were a number of ceramics that were of a finer paste and were either red or grey in color. They were decorated mostly using an impressed corded design or incised lines. In terms of pottery forms, there were large numbers of large mouthed, deep bellied *guan,* flat bottomed bowls, and high necked *hu* vessels and footed vessels, which show close similarities to those unearthed at sites of the Yingpanshan culture. The stone tool technology associated with this layer was composed largely of microlithic blades and cores.

Very few ground stone tools were unearthed. This changes with the transition to the Baodun period at which point these pottery types and microliths, disappear from the record. The assemblage from the Yingpanshan phase of the site shows marked differences from those of the Baodun culture leading the excavators to believe that these layers date to somewhat earlier (Wan Jiao: Personal Communication). Radiocarbon dates have been sent for analysis at Peking University, however, we are still waiting for results from this phase. According to Lei (Personal communication: 2012), dates from the laboratory at the Chinese Academy of Social Science have dated this level to c. 4000 BC, however, it is likely that these dates were carried out on wood charcoal.

The second phase of Neolithic remains are consistent with remains from other middle period Baodun sites unearthed from the Chengdu Plain. Remains from this phase were distributed in layer 5 in the western and southern area of the site (remains from this phase include one kitchen stove, 1 ditch covered in ashy deposits, a single tomb and 19 ash pits). Remains of pottery in this phase change to the black/brown, brown or red/brown pottery with sandy inclusions that is typical of the Baodun period. This pottery is characterized by a wide range of surface decoration, mostly of the corded variety. In terms of stone tools, the assemblage switches in this period to ground stone tools such as small stone adzes (*ben*) and axes (*fu*), grindstones and a few knapped stone tools.

6.6.1) Results of the Archaeobotanical Investigation

Samples from the Guiyuanqiao site were analyzed at a field station in Yibin County and at the Sichuan Provincial Institute of Archaeology. In H33 and H43, the two units dating to the Yingpanshan period, only foxtail and broomcorn millet are present. There is a large dominance of broomcorn millet over foxtail millet in these samples (Figure 6.7). Interestingly, *Chenopodium* is also present in the samples from this period and in one sample it appears in a rather high proportion. It is possible that this weed may have been consumed by the inhabitants of the site. This pattern changes in units that transition to the Baodun period (c.2700-2000 BC) (H25 and H9 and 2009SGTN03E03(4)), where rice appears in the record along with the continued presence of foxtail millet and broomcorn millet, whose numbers decrease substantially.

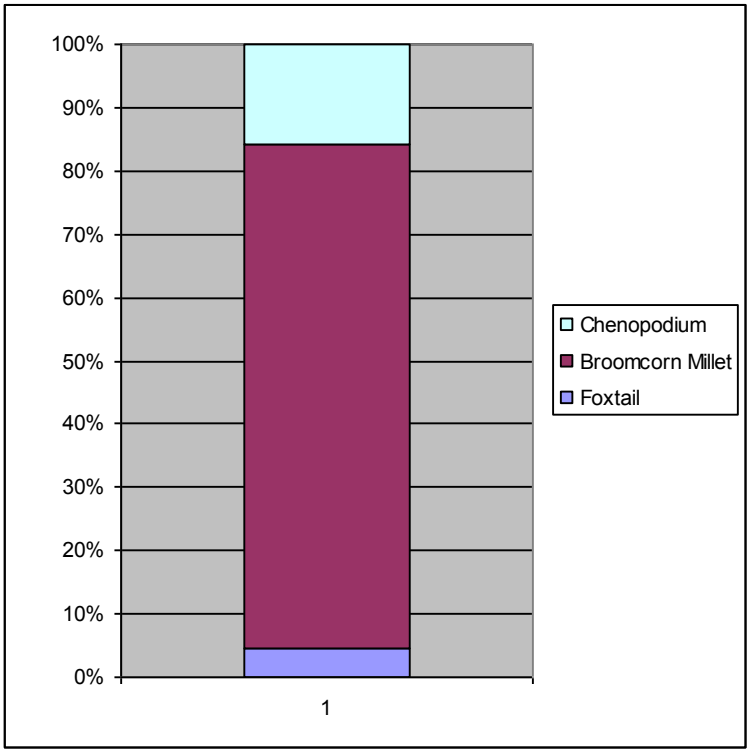

Figure 6.7 The proportion of broomcorn millet, foxtail millet and *Chenopodium* sp. at Guayuanqiao based on total counts

The predominance of broomcorn millet in these samples is also interesting and is worth discussing in light of the results from the site of Changdu Karuo and Yingpanshan. An analysis of crop proportions reveals that the inhabitants of Guiyuanqiao preferentially exploited broomcorn millet in a higher proportion than foxtail millet. In the layers that follow at the site of Guiyuanqiao, rice overwhelmingly forms the majority of the assemblage. The discovery of Yingpanshan layers along with evidence for millet exploitation indicates that the millet farmers from highland western Sichuan also exploited the lowland environment of the Chengdu Plain.

6.7) Spread of Millet Agriculture to Yunnan-Guizhou and SE Asia

The spread of millet agriculture into the region is much less well documented than is that of rice, and this is likely due in large part to sampling strategies as well as to issues of preservation (noted above).

The use of a large mesh sieve or hand picking favors the recovery of rice. Millets are much smaller and can rarely be seen by the naked eye during the course of an excavation. The apparent underrepresentation of millets in the archaeological record of Southwest China may thus be an artifact of sampling strategies as much if not more than of preservation (Weber & Fuller 2008). In fact, it is likely that the millets were some of the earliest crops to move into the highlands of Yunnan-Guizhou (d'Alpoim Guedes 2011; Xue 2010) and Southeast Asia (Weber, et al. 2010; Weber and Fuller 2008). More systematic sampling at Karuo and other early sites would allow paleoethnobotanists to determine if similar patterns hold true for the Tibetan Plateau. The short growing seasons (Table 5.6) and low labor input associated with millets allowed small scale

farmers to maintain a reliable plant food source while remaining at least seasonally mobile and to allocate large portions of time to foraging and hunting.

In addition to the sites mentioned above, foxtail millet has been reported at all sites where systematic flotation has been carried out in Guangxi, Guangdong and Southwest China. These include the Bronze Age sites of Haimenkou (1600-400 cal BC)(Xiao 1995; Xue 2010; Yunnan Sheng Wenwu Kaogu Yanjiusuo 2009) and Shifodong in Yunnan (1500-1000 cal. BC) (Zhao 2010d), as well as Gantouyan in Guangxi (1900-1200 cal BC) (Guangxi Zhuang Zizhiqu Wenwu Gongzuodui and Napo Xian Bowuguan 2003) (Figure 6.2). Recent evidence from Central Thailand suggests that millet agriculture may have preceded the spread of rice agriculture into Southeast Asia (Weber et al. 2010). More systematic flotation and sampling of archaeological sites may show that the same is true for Yunnan and Guizhou.

6.8 Agricultural Strategies in the Spread of Millet Farming

Early farmers moving throughout highland southwest China used a variety of different agricultural strategies to optimize their yields. Different proportions of foxtail and broomcorn millet are present in the assemblages discussed in this chapter. Several possibilities exist that can explain these differences in the proportion of foxtail and broomcorn millet across sites. The first may be an issue of preservation. Foxtail millet produces higher numbers of seeds than does broomcorn millet, and this may explain its higher representation in the assemblage (Baltensperger 1996). However, foxtail millet grains are smaller in size than those of broomcorn millet. Experimental work has shown that because of their higher surface area, seeds of smaller sizes are more readily destroyed during the carbonization process. Given this, one would except

foxtail millet to be more subject to destruction via carbonization (Castillo 2011; d'Andrea and Catherine 2008; Märkle and Rösch 2008). However this does not explain the much higher representation of foxtail millet at the site of Karuo.

A clear pattern is present when one examines the proportions of these crops according to altitude.

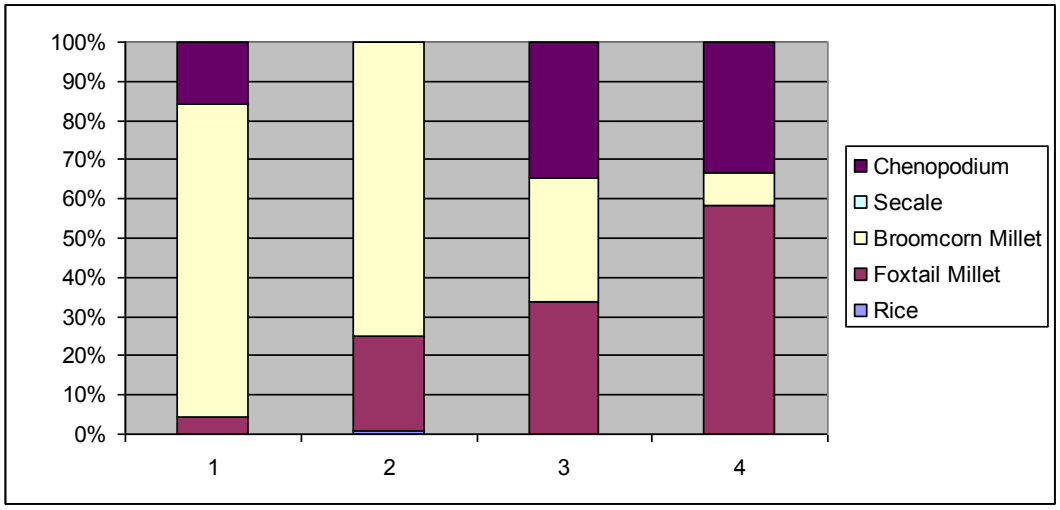

Figure 6.8 Proportions of different domesticates at sites across Southwest China organized according to altitude 1= Guiyuanqiao (alt. 526 m); 2=Zhongba (alt.660), 3= Yingpanshan(alt. 1500 m), 4= Karuo (alt. 3200 m).

Foxtail millet presents several important phenological differences with broomcorn millet, as discussed in chapter 5. Broomcorn millet has a shorter growing season (60-75 days) than foxtail millet (75-90 days). While foxtail millet can withstand arid conditions, its short root system means that it does also not recover well after droughts. Broomcorn millet is generally grown as a short-season crop and as a summer catch crop and can be planted from May to July. Given the short growing season, it may have seemed reasonable for the occupants of Karuo to have

selected broomcorn rather than foxtail millet as their primary basis of subsistence. Broomcorn millet requires moderately warm weather for good plant growth and has no tolerance for frost. In general broomcorn millet will not germinate at temperatures below 10° C or above 45 °C (Kamkar, et al. 2006; Theisen, et al. 1978). An optimum germination rate is achieved at around 40° C. Germination rates increase exponentially between 20 and 40 °C, however drop sharply after 45°C. Foxtail millet requires slightly lower temperatures for germination and reaches optimum germination at 35° C and productive germination occurs between 20° C and 35°C. Like broomcorn millet, temperatures above 43° C or below 10 will halt germination (Kamkar, et al. 2006). This may explain its less intensive use at the site of Karuo (Baker 2003). Foxtail millet can thus somewhat withstand cooler temperatures than broomcorn millet. If both crops were present in the repertoire of the inhabitants of lower altitude elevations of Eastern Tibet, then it is not curious that foxtail millet would have been preferentially consumed by the inhabitants of Karuo.

A look at figures 6.9 and 6.10 shows that the predicted niches occupied by broomcorn and foxtail millet far exceed those of rice. Some interesting differences are, however, apparent between the two. While both broomcorn and foxtail millet occupy similar niches, some subtle differences exist between the extent to which each crop was able to be grown on the foothills of the Tibetan Plateau. Despite its short growing season, broomcorn has substantial heat requirements in order to maintain satisfactory growth requiring between 2145-2243 GDD for a growing season. Foxtail millet, on the other hand, requires between 2000-2100 GDD and as a result is able to occupy slightly larger areas of highland western Sichuan than broomcorn millet. This analysis also reveals that sites on the Tibetan plateau itself, such as Lhasa, do not present sufficient numbers of averaged growing degree days for broomcorn millet to grow. Lhasa, however, contains

enough averaged growing degrees for foxtail millet to be successfully grown. This may be why foxtail millet is present in higher quantities than broomcorn millet at Karuo. Higher resolution weather data is needed from the Eastern Tibet in order to test this hypothesis.

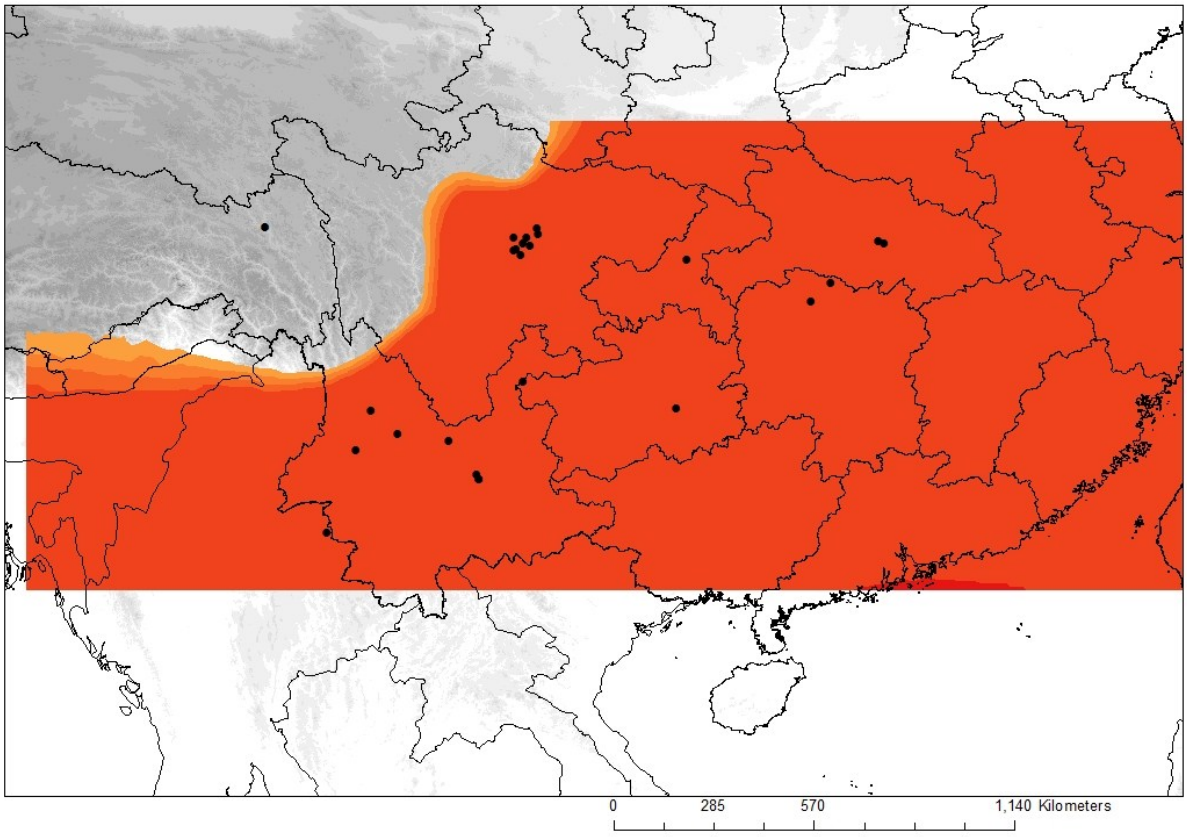

Figure 6.9 The potential distribution of broomcorn millet. Map created on a 5.5°C base. Broomcorn millet is reported as requiring between 2145-2243 GDD.

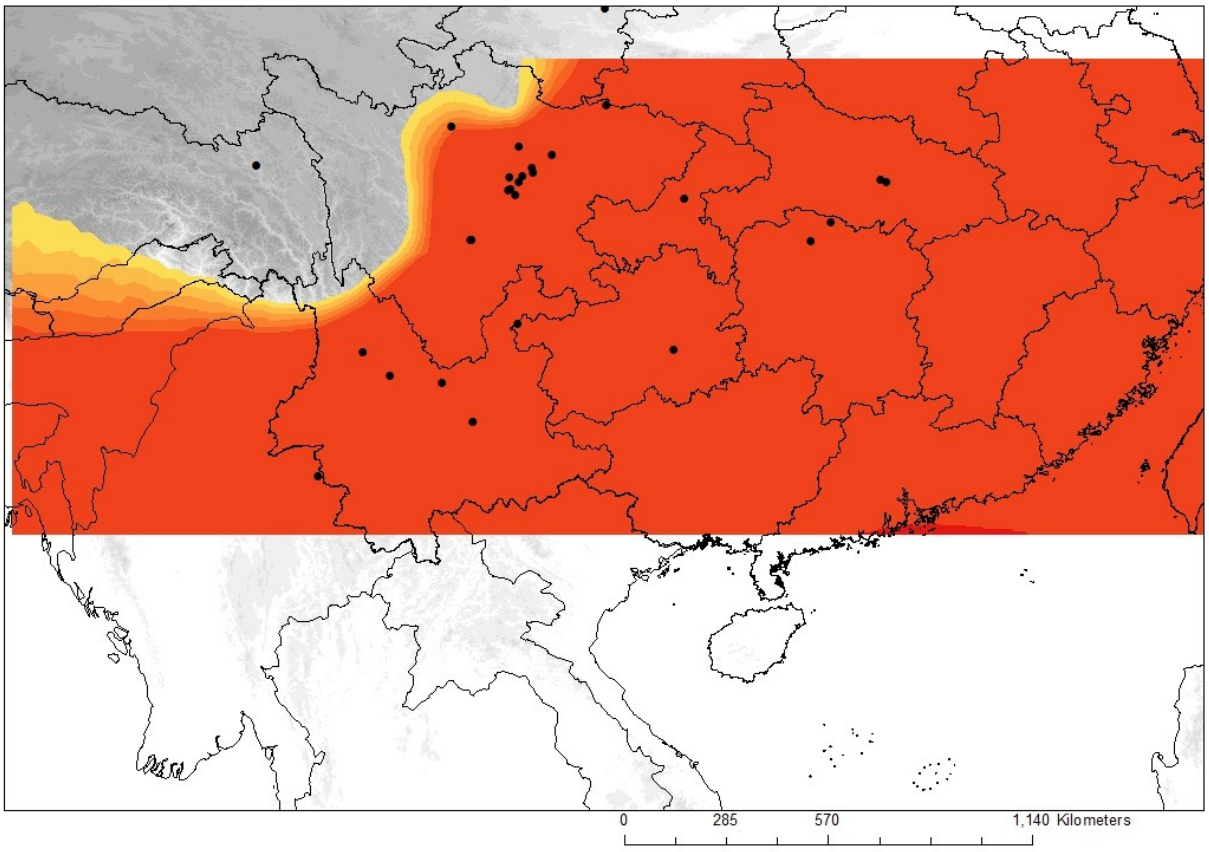

Figure 6.10 The potential distribution of foxtail millet. Map created on a 5.5 °C base with a 30°C threshold. Foxtail millet is reported is requiring between 2082-2191 GDD.

An analysis of risk of both crops reveals a similar pattern (Figure 6.11 and 6.12). From Lhasa to Songpan, although it is possible to grow broomcorn millet, a 70-80 percent chance of crop failure exists across this belt. In Deqin, Litang and Ganzi, the risk of failure is even higher and rises to 80-90 %. The risk of growing foxtail millet in the same area is considerably lower (between 32-45% in a belt reach from Lhasa to Ma'erkang and between 45-56 % around Songpan. In Deqin, Litang and Ganzi, there is a 56-66 % chance of failure. At Haxiu, the conditions for growing both types of millet are roughly equal and the risk of growing both

broomcorn millet and foxtail millet ranges from 32-45 % and at Yingpanshan, roughly similar conditions prevail.

The analysis of risk combined with growing degree days as well as an examination of crop phenology reveals that although foxtail millet has a longer growing seasons, its lower cumulative temperature requirements should have made it the crop of choice in highland western Sichuan and the Tibetan Plateau. In the area surrounding Changdu Karuo, while the risk of growing foxtail millet was high (between 75 to 82 percent), the risk is still lower than for broomcorn millet. In reality, the risk factor for foxtail millet in these areas may have been lower, as the two points in western Sichuan with particularly cold temperatures may be drawing the values here down. Broomcorn millet, on the other hand, presents a much higher risk of failure at high latitude and cool temperatures. At the site of Karuo, its risk of failure lies between 90-100 %. It is interesting to note that around the time Karuo was occupied (c.3500-3000 BC) corresponded to a considerable warming period and lake levels on the Tibetan plateau are higher (Li 1983). The abandonment of the site of Karuo corresponds closely to the 4.2 ka cooling event.

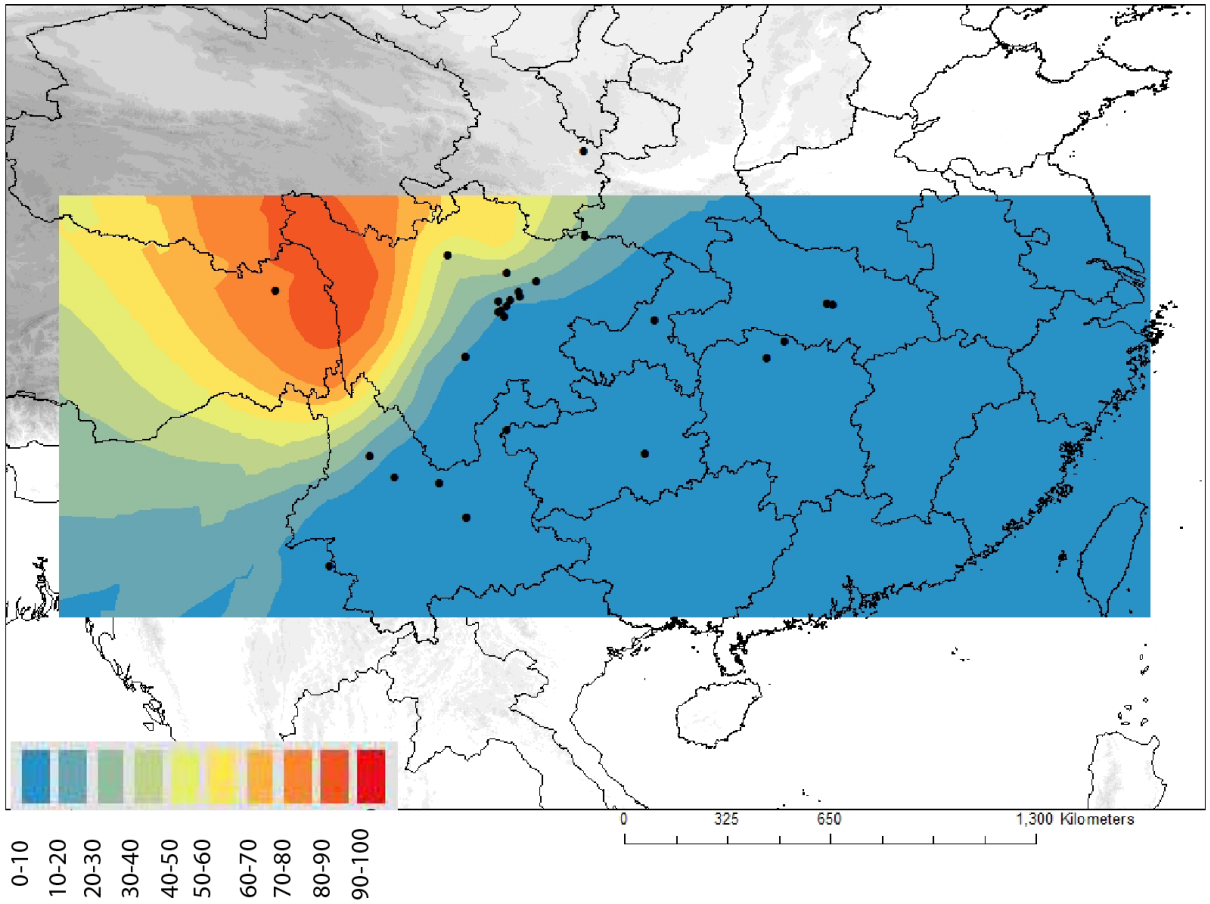

Figure 6.11 Risk map of foxtail millet. Data processed using a 5.5 °C lower threshold and a 30°C upper threshold. Numbers represent the total percentage of years where failure occurred.

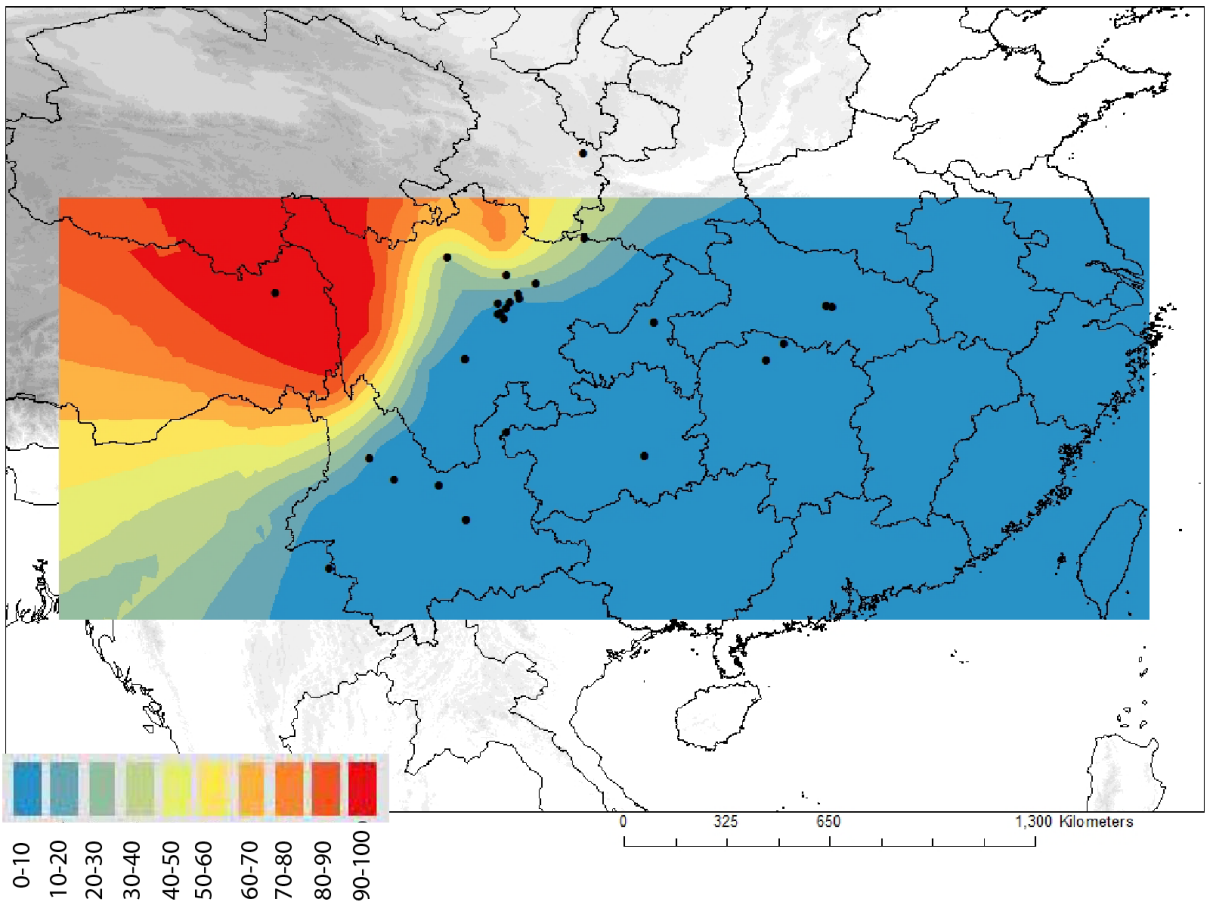

Figure 6.12 Risk map of broomcorn millet Data processed using a 5.5° C lower threshold and a 30°C upper threshold. Numbers represent the total percentage of years where failure occurred.

As I have suggested elsewhere (d'Alpoim Guedes 2011; Weber and Fuller 2008) because of their short growing seasons and tolerance to aridity, millets served as pioneer crops that facilitated the movement of agriculture into these more challenging environments. Indeed, we have demonstrated in this chapter that these millets were able to occupy a much larger area than rice. The earliest movement of agricultural products into Southwest China appears to have been based on millet agriculture. However, broomcorn and foxtail millet have important differences in their

phenological patterns and as a result the success with which ancient agriculturalists were able to exploit these crops depended largely on ecological conditions. Foxtail millet appears to have been preferentially exploited at sites in areas of high altitude and cooler climate, whereas broomcorn millet agriculture expanded in areas of warmer climate.

An analysis of GDD demonstrates that neither crop was ideally adapted for growth in the highland areas of the Tibetan plateau; however more accurate data are needed to test this hypothesis. This may explain why western domesticates, such as barley, eventually became the crops of preference on the Tibetan plateau. It is possible that a settled lifestyle on the plateau was only possible following their introduction. In these areas of high risk, populations that were familiar with hunting and gathering may have continued to exploit the wide range of tubers (such as drolma (*Potentilla* sp.), wild seeds (*Chenopodium* sp.) and the wide array of nuts and fruits that grew wild in this areas such as pine nuts (*Pinus* sp.), and berries (*Rubus* sp.). In areas of lower altitude such as Yingpanshan, the presence of wild fruits and nuts such as the peach (*Prunus persica)*, Chinese plum (*Prunus mume*), Chinese apricot (*Prunus armeniaca*), walnut (*Juglans* sp.), wild species of grape (*Vitis* sp.) and common sea-buckthorn (*Hippophae rhamnoides)* may have formed important additions to the diet.

6.9 Crops, languages and population movement in Southwest China

The evidence discussed in this chapter suggests that the spread of an agricultural lifestyle into Southwest China was closely tied to southward movement of peoples associated with the Majiayao expansion. Pottery analysis carried out by Hung et al. (2011) suggests that these people

maintained close ties with the Majiayao heartland and directly traded painted pottery with populations living further to the north. Non prestige wears, were, however, found to be of local manufacture, although some of these also shared similarities to the repertoire of Majiayao sites in Northern China. What should one make of the relationship between these sites and sites in northwest China? Was an agricultural lifestyle uptaken by local hunter-gatherer populations or was there a wholescale movement of agriculturalists from the Majiayao heartland into Southwest China? Using evidence from another group of sites outside of the Majiayao cultural heartland (Zongri in Eastern Qinghai) she suggests that changes in burial ritual show that both immigrant and local populations bought into the ideology that accompanied these painted vessels and placed them in their tombs. Immigrant populations, which were hypothesized as bringing both agriculture and painted pottery vessels with them, were buried in extended supine positions, whereas local hunter-gatherers were buried in a prone position (Hung 2011). Isotopic studies carried out that these sites also show that individuals buried in the prone position showed an increase in C4 values overtime, suggesting that millet played an increasingly important role in their diet (Cui, et al. 2006).

Thus far, very few burials have been unearthed in sites dating to this period in Southwest China, however, future research can help us disentangle the identity of the individuals that moved agriculture into highland Southwest China, and their relationship to local hunter-gatherer populations. If the continued presence of microliths in Southwest China are any clue to the nature of these relations, it is possible that local hunter-gatherers in the region (that were once big game hunters) began to adopt an agriculture lifestyle following increased cultural contact with populations in northwest Gansu and Qinghai.

On the Tibetan plateau at Karuo, it seems that local hunter-gatherers who continued to use a large part of their original pottery and stone tools repertoire, began to experiment with millet agriculture, which allowed them to maintain their mobility. Experimentation with broomcorn and foxtail millet appears to have been a dynamic process, and these crops were used interchangeably by farmers according to the ecological niche they occupied. The reasons hunter-gatherers in this region began to carry out millet agriculture may have been similar to the reasons millet agriculture first began in northern China. The short growing season of these crops allowed game hunters to maintain a high degree of mobility. Although it is unclear which came first, the adoption of domestic pig probably played an important role in the transition to a more sedentary lifestyle. Until more excavations and further research is brought to bear on this question, these remain for the moment fascinating possibilities.

Summary

The evidence for hunter-gatherer occupation in southwest China as a whole is lacking, however I argue that this is likely a facet of the lack of research in this region. Millet agriculture is the earliest form of agriculture to spread to this region and is closely tied to the phenomenon of the Majiayao expansion. Millet agriculture first appears at Majiayao cultural sites in Western Sichuan c. 3500 BC and shortly after this date appears on the Tibetan Plateau at the Karuo site. Although further evidence is needed to test this hypothesis, it is also likely that millet agriculture was the first kind of agriculture to move into Southeast Asia. Differences are, however, present in the phenological properties of broomcorn and foxtail millet: the latter requires higher numbers

of growing degree days to achieve maturity and a higher temperature at germination and as a result was grown in higher proportions in lowland environments. Foxtail millet, on the other hand, was grown in higher proportions in areas of higher altitude such as on the Tibetan Plateau. The short growing season of both of these crops allowed them to be integrated into a lifestyle that combined mobility and foraging.

CHAPTER 7

THE SPREAD OF RICE AGRICULTURE: THE CASE OF THE SICHUAN BASIN AND THE YUNNAN-GUIZHOU PLATEAU

The spread of rice agriculture out of its original homelands of domestication in the lower and possibly middle Yangzi river valley was a slow process. The spread of rice agriculture changed the landscape of southwest and southern China forever and transformed this area from a continent of hunter-gatherers to a land of agriculturalists. Because domesticated varieties of rice could sustain high population densities, the spread of rice agriculture led to profound changes in social structure and social complexity (Fuller and Qin 2009).

The identity of the movers of rice agriculture outside of its original homelands is unclear, and archaeological evidence has not been able to establish whether moving agriculturalists or acculturated hunter-gatherers were responsible for its spread. Several authors have argued that the spread of rice agriculture outside of its original homelands also played an important role in the movement of peoples and languages (Bellwood 2005a; Hingham 2002; Sagart 2008; Starosta 2005; van Driem 2002).

Several linguistic models exist for explaining how this spread occurred. Sagart (2008) proposes that groups originated in the Yellow River valley who were speakers of PSTAN (Proto-Sino-Tibetan Austronesian) and who grew rice and millet, diversified into two different groups: a.) one that moved west and became the speakers of Proto-Sino Tibetan languages (that may b associated with the Yangshao expansion); and, b.) a group that moved east along the coast and to Taiwan, via the lower Yellow River valley, that eventually became the speakers of AN

(Austronesian Languages) and carried both rice and millet agriculture as they spread. Much debate has focused on identifying the individuals associated with the movement of Austronesian languages from Taiwan into island Southeast Asia but I do not further discuss this issue here (see (Bellwood 2005), especially as this model does not provide evidence for how rice agriculture may have spread into Southwest China.

Models proposed by Van Driem (2005) argue that speakers of Tibeto-Burman languages that lived in Sichuan and Gansu, moved across the Himalayas between 3900-1800 BC). In his model, the speakers of these languages then settled in the Sichuan basin (c. 1500-1000 BC) and, following increases in population density in this area during the Bronze Age, moved out to occupy Yunnan-Guizhou and South East Asia.

An additional, but lesser known language group, Hmong-Mien, is also hypothesized to have played a role in the spread of agriculture to Central China (Starosta 2005). Today Hmong-Mien languages are found scattered in mountain pockets throughout Yunnan, Guizhou, Vietnam, Laos and Thailand. While some have hypothesized that these may the remains of languages spoken by hunter-gatherer groups in these areas, others (Starosta 2005) believe that their fragmented distribution is the result of an expansion powered by agriculture, followed by being in the path of other people's successful expansions. Starosta (2005) believes that this spread took place relatively late, c. 770-223 BC, and coincides with the expansion of the state of Chu outside of its middle Yangzi homeland.

However, Fuller (2012) argues that an expansion associated with Hmong-Mien languages may have occurred even earlier. He argues that Hmong-Mien speakers should be associated with the Daxi culture (c. 4000 BC). Speakers of an unknown language (presumably some variant of

Hmong-Mien, although he does not specify) moved rice and foxtail millet agriculture south and westward, interacting with speakers of Austro-Asiatic (AA) languages to the South. This chapter reviews the archaeological evidence for the spread of material culture and for early agriculture to Southwest China and I consider these in light of these linguistic arguments.

Using an approach based in ecological niche modeling, I also discuss how humans adapted rice based agricultural systems to the upland environments of southwest China and the effects that this new environment had on their movement. The expansion of rice agriculture into Southwest China as a whole largely postdates 3000 BC, leaving a gap of almost 3000 years between its domestication farther east on the Yangzi and its arrival in Southwest China (Zhang & Hung 2010). Compared to the spread of rice agriculture along the Chinese coast and to the north (Crawford et al. 2005; Crawford et al. 2006), the spread into Southwest China occurs at a much slower rate, the reasons for which are important to consider. This chapter presents the archaeobotanical evidence for the earliest known spread of rice agriculture to this region. This evidence comes from sites of the Baodun culture (2700-1700 BC) in the Chengdu Plain of Sichuan Province. Following a discussion and presentation of the evidence from Baodun, I discuss some hypotheses for the mechanisms underlying the spread of agriculture to the Yunnan-Guizhou plateau.

7.1) The Spread of Agriculture to the Sichuan Basin

7.1.1) Spread of rice agriculture from the middle Yangzi to the Three Gorges

Archaeological sites to the east of the Sichuan Basin contain important evidence for trying to understand how the spread of rice agriculture into this region could have occurred. Cultures of the middle Yangzi form an important lynchpin in understanding how this spread occurred. The Chengtoushan site in Lixian County, Hunan, contains evidence for evaluating the direction of the spread of agriculture into this region. Chengtoushan shows multiple episodes of occupation, the earliest levels dating to the Tangjiagang culture (ca. 5000–4400 cal BC). These levels of occupation are immediately followed by a Daxi culture occupation (ca. 4400–3300 cal BC). During the later Qiujialing period (ca. 3300–2500 cal BC), a large moat enclosing an area of roughly 100,000 m^2 was built and continued to be used throughout the Shijiahe culture phase (ca. 2500–2000 cal BC). A number of studies from recent years have shown that during the early Daxi period, rice agriculture was a staple of subsistence of the inhabitants of the site (Nasu, et al. 2011; Nasu, et al. 2007; Yasuda, et al. 2004). In 2001 and 2002, macrobotanical samples were collected from the Daxi period construction of the moat by Nasu et al.(2007) and they discovered that from about 3800 BC, foxtail millet was combined with rice agriculture at this site. This shows that a part of the repertoire from northern China had already been incorporated into the subsistence regime of the south. It is worth noting, however, that the numbers of foxtail millet specimens present at the site of Chengtoushan are extremely low, and this crop thus probably did not form an important component of the diet.

The Three Gorges region of Eastern Sichuan contains evidence of connections with sites of the middle Yangzi from early times onward: The discovery of the sites of Chaotianzui and Liulinxi in the Eastern Three Gorges, show that the occupation of this area may date to as early as 7200-5000 BC. The early strata of these sites contain cultural material that is very similar to that of the

Chengbeixi culture (7200-5000 BC) of the middle Yangzi River valley (Flad 2013; Gao 1998). In the western part of the Three Gorges, pottery vessels from the lower levels of Yuxi and Yuxiping show clear connections to those of the Chengbeixi culture in the Hubei Basin, leading the excavators of this site to believe that it could date to as early as 6000-5000 BC (Chongqing Shi Wenwu Kaogusuo 2003, 2006). While sites of the Daixi culture (4300-3300 BC) are mostly distributed throughout the low lying areas of the middle Yangzi, the Daixi type site itself is situated in the eastern Three Gorges area (Flad 2013; Sichuan Bowuguan 1981; Sichuan Sheng Changjiang Liuyu Wenwu Baohu Weiyuanhui Wenwu Kaogudui 1961).

Although no archaeobotanical analysis has ever been carried out at these sites, the large amounts of fish bones founds in excavations of Yuxiping culture sites, lead Zhang and Hung (2008; 2012) to hypothesize that between 6000-4400 BC the Three Gorges and Xia Jiang area was occupied by hunter-gatherers whose subsistence focused on fishing similar to those found in the Pearl River delta in southern China. For instance, all sites of the Gaomiao culture, although showing close cultural ties to the agricultural Daxi culture, are shell middens that contain large numbers of freshwater gastropods, other aquatic animals and game. Rice impressions have been uncovered on some pottery sherds relating to sites of this culture (including from the site of Gaomiao itself) (Gu and Zhao 2009) however, as no systematic flotation has been carried out in this region, it is difficult to know if the absence of agricultural products truly reflects that the inhabitants of this culture were still hunter-gatherers or rather the lack of flotation carried out in this area as a whole. Although no flotation has been carried out on Daxi period sites in the Eastern Sichuan Basin and the Three Gorges area, evidence from the Daxi culture site of Chengtoushan in the Middle Yangzi suggests that they may have practiced both rice and foxtail

millet agriculture. Indeed, Zhang and Hung (2010) hypothesize that rice agriculture spread to the Sichuan Basin from this region. The lack of archaeobotanical analysis in the Three Gorges as a whole makes it difficult to understand if agriculture had indeed already moved into this area by the forth millennium BC.

Sites of the Shaopengzui culture (c.4300-2500 BC) in the Three Gorges area continue to show clear connections with sites of the Middle Yangzi, in particular with those of the Qujialing (3000-2500 BC) and Shijiahe (2500-2000 BC) cultures, especially in terms of pottery repertoire, namely the presence of large urns and beakers with horizontal appliqué design and small vats. Sites of the Shijiahe culture contain some of the only archaeobotanical evidence for understanding the transition to agriculture in the Three Gorges, but they are rather late in date. As discussed in chapter 6, the earliest evidence for agriculture in the Three Gorges comes from the early phases of the site of Zhongba and dates to 2500-1750 BC (Zhao and Flad ND). Despite signs of some cultural connections with rice producing sites of the Middle Yangzi, the archaeobotanical remains from Zhongba show a clear reliance on broomcorn and foxtail millets. Only a single fragmentary grain of rice was unearthed from early deposits from this phase. As discussed in chapter 6, it is possible that the vertical topography, saline soils and cooler temperatures found in the Zhongba area may have presented a challenge for creating the water management systems associated with rice paddy agriculture, thus prompting the use of dryland crops. Indeed the presence of a single grain of rice suggests that the inhabitants of this site were familiar with this crop, even though they did not cultivate it. The presence of domestic animals like pig in the earliest layers of the site, along with an intensive hunting and fishing component, further suggest that an agricultural lifestyle was already established in this region by this point in

time. The introduction of systematic flotation to archaeological work in Three Gorges and Eastern Sichuan Basin will likely clarify how the inhabitants of sites that shared close connections to the Middle Yangzi adopted an agricultural lifestyle.

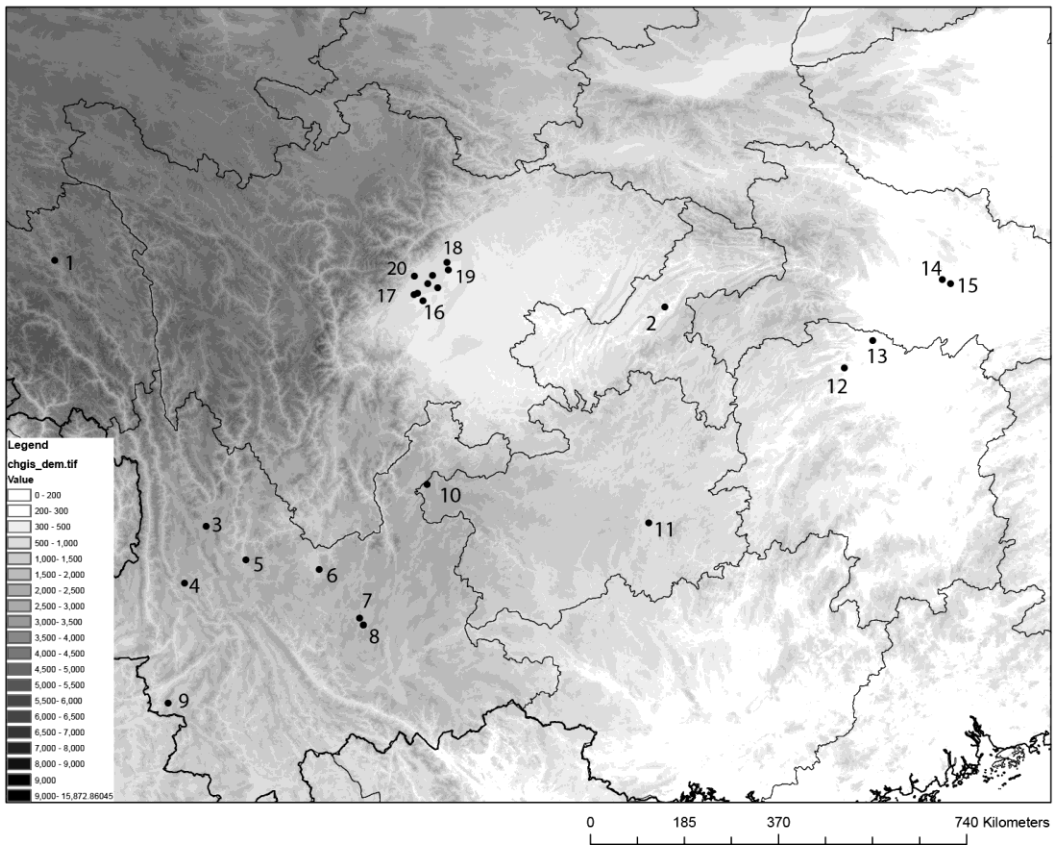

Figure 7.1 Main sites discussed in the text: 1) Changdu Karuo; 2) Zhongba; 3) Haimenkou; 4) Yongping Xinguang; 5) Baiyangcun; 6)Dadunzi; 7) Dongan; 9) Haidong; 8) Shizhaishan; 9) Shifodong; 10) Jigongshan; 11) Mopandi; 12) Chengtoshan; 13)Pengtoushan; 14) Qujialing; 15) Shijiahe; 16) Baodun, 17) Shuanghecun; 18) Guiyuanqiao; 19) Sanxingdui; 20) Mangcheng

7.1.2) The Western Sichuan Basin: Insights from the Site of Baodun

Although it is highly likely that earlier evidence exists in the Three Gorges region, the earliest evidence for rice agriculture in Southwest China comes from sites of the Baodun culture in the western part of the Sichuan Basin. Aside from recent finds at the site of Guiyuanqiao (discussed in chapter 6) there is little evidence for any intensive occupation of the Chengdu Plain prior to Baodun (2700-1700 BC). Sites of the Baodun culture appear suddenly on the Chengdu Plain at around 2700 BC. At their earliest appearance on the Plain, these sites are already large in size, surrounded by large walls, and contain a fully formed pottery repertoire that differs substantially from that of surrounding regions, leading to some discussions as to their origins. Given the sudden arrival of the Baodun culture on the Chengdu plain c. 2700 BC and the absence of any obvious antecedent, its origins have been the subject of much debate (Huang & Zhao 2004; Flad and Chen 2006; Flad and Chen 2013; Jiang 2001; Zhang and Hung 2010).

The lack of evidence for hunter-gatherer occupation in this area is surprising. Although geomorphological remodeling in this alluvial fan may have hidden or destroyed the evidence, it is astonishing that over five years of systematic survey in the Chengdu plain have failed to document any prior hunter-gatherer occupation (Chengdu Pingyuan Guoji Kaogu Diaochadui 2010). As a result, scholars have been silent on the potential role played by such populations in this spread of agriculture, hypothesizing that the Baodun culture was established by agriculturalists migrating into the region (Huang and Zhao 2004; Jiang 2001; Zhang and Hung 2010).

The origins of the Baodun culture have been the subject of much discussion.To date, similarities in pottery typology have frequently been used to approach this question. Some scholars believe

that the Baodun culture is an independent development on the Chengdu Plain and is unrelated to surrounding cultures (M. Li 1999), but the pottery record at sites of the Baodun culture shows some connections to sites surrounding the Chengdu Plain. In particular, Jiang et al. (2000) believe that the long necked jars with trumpet shaped mouths share similarities with sites of the later Shaopengzui culture in the Three Gorges (3000-1800 BC), particularly as seen at the Weijialiangzi site (c. 2700-2000 BC). Others (Huang and Zhao 2004) believe that the Chengdu Plain pottery forms and their decoration share similarities with sites of the Yingpanshan culture. Newly unearthed evidence from the site of Guiyuanqiao summarized in chapter 6 shows that the first settlers of the plain shared very close connections to the Yingpanshan culture, and we have already demonstrated that they practiced millet agriculture. The connection between these early remains at Guiyuanqiao and the Baodun culture itself, however, remain unclear.

Similarities in ceramic decoration, shape, and manufacture has led some scholars to suggest that the Baodun culture could have originated from the spread of Majiayao millet agriculturalists from the highlands of western and northeastern Sichuan into this area (He In Press; Huang and Zhao 2004; Jiang 2001). Others have pointed to the walls surrounding sites of the Baodun culture as evidence of regional interaction with areas to the east (Flad and Chen 2006; Fuller and Qin 2009), where similar walled settlements have been found in sites of the Middle Yangzi River Valley such as those of the Taijiagang Culture (c.4400 BC) and the Daixi culture (4300-2500 BC) (Hunan Provincial Institute of Archaeology and Cultural Relics 2007), as well as the Qujialing (3000-2500 BC) and the Shijiahe culture (c. 2500-2000 BC) (Beijing Daxue Kaogu Xi, et al. 1992; Zhongguo Shehui Kexue Yuan Kaogu Yanjiusuo 1965), all of which were supported by rice agriculture. This has led several scholars to hypothesize that the arrival of the Baodun

culture on the Chengdu Plain is the result of the expansion of rice agriculturalists into the region (Fuller and Qin 2009; Zhang 2008; Zhang and Hung 2010)

7.1.3) Characteristics of the Baodun culture

A settlement pattern consisting of small hamlets and homesteads surrounding large walled sites characterizes this period of occupation of the Plain (Chengdu Pingyuan Guoji Kaogu Diaochadui 2010; Chengdu Shi Wenwu Kaogu Yanjiusuo 2004a, d, 2005a, 2006a, b, c; Chengdu Shi Wenwu Kaogu Yanjiusuo and Pixian Wenwu Guanlisuo 2005; Chengdu Shi Wenwu Kaogu Yanjiusuo and Xindu Qu Wenwu Guanlisuo 2010). To date, 10 walled sites have been discovered, which range from 7-245 ha in size (see table 7.1) (Chengdu Shi Wenwu Kaogu Gongzuo Dui 2001a, b; Chengdu Shi Wenwu Kaogu Gongzuo Dui and Pixian Bowuguan 1999; Chengdu Shi Wenwu Kaogu Gongzuo Dui, et al. 1998; Chengdu Shi Wenwu Kaogu Yanjiusuo, et al. 2000; Yan and Jiang 1999; Zhongri Lianhe Kaogu Diaocha Dui 2001).

Table 7.1 Sizes of enclosed areas of walled sites of the Baodun culture

Site Name	Site Size (ha.) estimate
Baodun	25
Baodun (outer wall)	245
Mangcheng	7.2
Guchengcun	30.4
Zizhucun	20
Shuanghecun	11
Yufucun	40

These include the sites of Baodun in Xinjin County, Mangcheng in Dujiangyan city, Guchengcun in Pixian, Yufucun in Wenjiang, Shuanghecun and Zizhucun in Chongzhou, the site

cluster at Sanxingdui in Guanghan, and Huachengcun in the city of Chengdu. The function of these walled settlements is unclear, but Flad and Chen (2013) argue that the low slope of the walls may indicate that their function was not defensive and suggest these walls may have served as protection from flooding. These walls differ in construction techniques from those seen in Northern China, where walls were constructed using wooden planks to support earth, which was piled and then stamped into place. In the Chengdu plain, it appears that these walls were constructed by vertically and horizontally piling earth clods. The scale of these enclosures and the labor required to build them hints at the beginnings of social complexity in the region. The sheer volume of soil used to create these walls indicates that a sustained, collective and organized effort was necessary to create these walls, one that was likely supported by a reliable agricultural subsistence base (Flad and Chen 2013). Recent fieldwork carried out at the site of Baodun itself has shown that the site was enclosed by two large walls enclosing 66 and 245 hectares respectively. Systematic augering and small scale excavations at different locations along the remains of this wall have shown that the outside wall was built after the first wall, during the final phase of site occupation, or at the beginning of phase 2 of the Baodun culture. Flad and Chen (2013) argue that the scale of labor required to build these walls was not monumental, but still required a sustained and collective effort; they therefore suggest that these walls represent an important shared labor practice among Baodun communities. By calculating the amount of time it would have taken an individual to move a certain volume of soil, Flad and Chen (2013) estimate that the walls could have been built by only several score or several hundred people working for over a year, but believes it is more likely that several thousand people built these walls over a period of a few months. Many of the sites of the Baodun culture are larger than those occupied by other cultures found in the vicinity, including the walled site at

Chengtoushan, which by comparison covers a mere 15.2 ha, hinting that these sites may have supported high population densities with the ability to harness considerable labor.

Only small scale excavations have been carried out at these sites, and as a result their internal organization is somewhat unclear. House remains have been unearthed at Baodun, Mangcheng, Gucheng and Yufucun. The alignment of postholes observed at the site suggest that these houses were square in shape, and the recovery of large amounts of burnt clay containing impressions of bamboo slats show that they were built using wattle and daub technology (Jiang, et al. 1997). Some of these houses were well preserved, particularly one from the site of Mangcheng (Yan and Jiang 1999; Zhongri Lianhe Kaogu Diaocha Dui 2001). In between the houses, finds of large amounts of ashpits (used for rubbish refuse) suggest that the area may have been relatively densely occupied. The find of a large rectangular structure at Pixian Gucheng indicates that these sites may have also served ritual or communal functions. This structure measured over 50 meters long and in its center five rectangular piles of stones were discovered in a row. These have been interpreted as either supporting posts or acting as ritual platforms (Chengdu Shi Wenwu Kaogu Gongzuo Dui and Pixian Bowuguan 1999; Chengdu Shi Wenwu Kaogu Yanjiusuo and Pixian Wenwu Guanlisuo 2001; Flad 2013).

Despite the obvious labor required to build these structures and the presence of communal or ritual buildings, there is no evidence for a ruling elite in the Baodun culture. All known burials from the Baodun site are simple pit burials and contain no visible evidence of stratification. This hints that a more communal rather than a hierarchical ethos may have governed society.

Major artifact types include coarse pottery with quartz sand inclusions and fine paste pottery. The color of the coarse paste sandy pottery with sandy inclusions ranges from grey to brown and red. Uneven firing means that much of this pottery is of a different color on the inside than on the outside. Fine paste pottery is represented by pieces that are whitish grey, grayish or brown. A smaller number of vessels are grey or brown pottery covered in a black slip, however at the time of excavation this slip was rarely well preserved. This coarse pottery is generally decorated using corded designs, however a substantial percentage of vessels also carry incised designs and *fujiaduiwen* (appliqué). A smaller percentage has scraped designs and *xianwen* (string design). These designs are usually placed along the rims, lips, necks, and on the bottom of the vessel. Coarse ware is, for the most part, represented by cord-marked jars or ring-footed beakers whereas the finer wear is usually dark in color, has a slip and has a wider repertoire of forms including long-necked jars with trumpet mouths, flasks with flat bases, wide-lipped basins, and the occasional stemmed bowls (Jiang, et al. 2000; Wang and Sun 1999). Although these data have not yet been published, excavations at Baodun in 2010 are reported to have yielded pottery showing close connections to those of sites in the middle Yangzi (He Kunyu: Personal Communication 2012).

The stone tool repertoire of the Baodun culture consists primarily of small ground stone tools. Very few knapped stone tools have been unearthed in the Chengdu plain, possibly because adequate natural resources of flint seem to be lacking in the area. Most ground stone tools were manufactured from local river pebbles. Common implements include adzes, axes and chisels. The limited repertoire of tools as well as their shape suggests that these tools were used to create wooden implements or architectural features. The discovery of shovels and other tools made out

of wood from the Bronze Age site of Jinsha in the Chengdu plain, further suggest that this may have been the case. A smaller number of ground stone or knapped knifes, shovels, spearheads and arrowheads have also been unearthed.

It is clear from both pottery chronology and radiocarbon dates that the walled sites of the Baodun culture were not all occupied contemporaneously. Sites of the Baodun culture can be divided roughly into four different phases (Jiang, et al. 2000). The site of Baodun is the earliest known site of this culture and three different phases of occupation are present at the site: phase 1 and 2 are related to what Jiang (2000) calls the Period 1 occupations. The latest phase of occupations at Baodun (Phase 3) fall into the second period of occupation. Thus far, only the site of Baodun itself and the remains from phase 1 of the Sanxingdui site fall into this time period. In the second period only the sites of Mangcheng and Baodun occupy the landscape. During the third period of occupation more sites appear on the landscape and during this period of time, a total of five walled sites: that of Pixian, Yufucun, Yueliangwan at Sanxingdui and Shuanghecun dominate the landscape (Table 7.2).

Table 7.2 Walled sites and phases they belong to on the Chengdu Plain on the basis of pottery chronology. After Jiang et al. (2000)

	Baodun	**Mangcheng**	**Pixian Gucheng**	**Yufucun**	**Sanxingdui**	**Shuanghecun**
Period I	**X**				**X**	
Period II	**X**	**X**				
Period III			**X**	**X**	**X**	**X**
Period IV			**X**	**X**		

7.1.4) Excavations and flotation samples from the site of Baodun

The Neolithic site of Baodun in Xinjin County is the type site for the Baodun culture and has been the object of several seasons of excavation. Two seasons of relatively small scale investigations at the site were carried out in 1995 and 1996. The site was first surveyed and preliminary excavations were carried out in 1995 by local authorities, while in 1996 the site was chosen to form part of a collaborative project with Waseda University. At the time, only one enclosure surrounding the site of Baodun had been discovered; it covered a surface area of roughly 25 ha. Both the north and east walls of this inner enclosure are still standing, however the south and west walls were largely destroyed. During these early seasons of excavation, a total of only 435 square meters were excavated and only few structures were recovered. One portion of the excavation focused on understanding the construction and dating of the wall. Two square wattle and daub houses were unearthed during this season, along with 24 ashpits and five poorly preserved tombs. Major categories of finds from the site of Baodun include a variety of ground stone tools, pottery and an arrowhead, which the excavators argue share similarities with the Qujialing and Shijiahe cultures to the north-east.

Because of its obvious importance, Baodun was selected as a target for reinvestigation as part of the Wenming Qiyuan Project (Origins of Civilization Project). Two seasons of excavation were carried out at the site during the winter of 2009 and 2010. A total of 364 sq. m were excavated at Baodun during two field seasons (He, et al. 2012).

Flotation samples were extracted from stratigraphic layers, ashpits as well as other visible structures like ditches. Samples from the Baodun site itself dated to phases 1 and 2 of the Baodun culture.

7.1.5 Flotation samples from other Baodun period sites

In addition to samples from Baodun itself, I also examined several samples relating to later phases of Baodun occupation of the Chengdu Plain. These included a sample from the Zhonghai site. I also include a review of Baodun period samples from the sites of Yongfucun, Xinjin Huayuan and Sanxingcun that were analyzed by Shi Tao at Peking University.

a.) The Zhonghai site

The Zhonghai site is located in northwest portion of the city of Chengdu. Excavations were carried out following its discovery during a prospection mission. The occupation of the Zhonghai site ranges from the Baodun period to the Bronze Age with a few later, Song dynasty tombs superimposing the earlier layers. Two seasons of excavation have been carried out at the site. The first season of excavation took place at locale 1 of the site, which covered a total of 12,600 square meters (Chengdu Shi Wenwu Kaogu Yanjiusuo 2007). A large number of Baodun period remains have been unearthed at this locale, including ashpits and the remains of house structures. Samples were collected from ashpit 30 of this site. Like the other ashpits unearthed at the site, the remains from this period were situated underneath level 5 of the site. Large numbers of Baodun period pottery were unearthed from this feature and direct dates on rice grains yielded a date of Baodun period (2210-2110 BC), which relates to the later part of the Baodun period or roughly phase 3-4 of the Baodun culture.

b.) Yongfucun

The site of Yongfucun is located in Wenjiang County and was excavated in 2010. Both late Baodun and Shi'erqiao strata were found at the site. Only 3 samples relating to the Baodun phase were extracted.

c.) Xinjin Huayuan

The Huayuan site was located in Northern Xinjin County and was excavated between 2009 and 2010 by the Chengdu City Institute of Archeology. A kiln and a number of ashpits dating to the late Baodun period were found at the site in layer 6. Layers 5 and above dated to the Shang/Zhou period.

d.) Sanxingcun

The Sanxingcun site is located in Qingbaijiang to the north of Chengdu City. Excavations were carried out at the site in 2003 and 2009. Deposits at the site date largely to the late Baodun (phases 3-4) and Sanxingdui periods. Samples relating to the Baodun period were extracted from level 5 of the site (samples dating to levels 3 and 4 pertained to the Sanxingdui period).

e.) Guiyuanqiao

Samples from layers dating to the Baodun period were also found at Guiyuanqiao, however as a complete analysis of materials from the site and radiocarbon dating had not yet been carried out at the time of writing we were unable to ascribe these to a given phase.

Table 7.3 Baodun period samples examined for this dissertation

Site	**Baodun Phases present**	**Number of Samples**	**Analyzed by**
Xinjin Baodun	1-2	35 (60)	Jade d'Alpoim Guedes (and Shi Tao)
Yongfucun	3-4	3	Shi Tao
Xinjin Huayuan	3-4	14	Shi Tao
Sanxingcun	3-4	2	Shi Tao

Table7.3 (Continued)			
Zhonghai	4	1	Jade d'Alpoim Guedes
Guiyuanqiao	?	7	Jade d'Alpoim Guedes
TOTAL		20	

7.1.6 Radiocarbon dating at the site of Baodun

AMS dates were carried out on rice grains and in one instance wood charcoal on samples from the 3 different Baodun phases and the Han phase of the excavations at the Baodun type site (Table 7.4). Dates were calibrated using Oxcal V 4.1.7 (Reimer et al. 2009).

Table 7.4: Uncalibrated Radiocarbon Dates and laboratory numbers for the site of Baodun. Dates are listed in stratigraphic order within each phase, archaeologically oldest context at the top of the list.

Lab No.	Stratigraphic Information	Phase	Date	Plant Part
BA110047	**T 1830 (5)**	Baodun Phase 1	3890±35	Rice
BA110048	**T 2426 (5)**	Baodun Phase 1	3830±30	Rice
BA110049	**T 2426 (5) H6**	Baodun Phase 1	4010±50	Rice
BA110050	**T 2431 (5)**	Baodun Phase 1	3730±30	Rice
BA110058	**T 2431 (4) H1**	Baodun Phase 1	4060±30	Rice
BA110059	**T 2431 (4) H1**	Baodun Phase 1	4000±30	Rice
BA110051	**T 1830 (4) H3**	Baodun Phase 1	3705±30	Rice
BA110061	**T 2431 (4) H11**	Baodun Phase 1	4005±30	Rice
BA110062	**T 2431 (4) H8**	Baodun Phase 1	4015±35	Rice
BA110060	**T 2431 (4) H2**	Baodun Phase 1	3885±30	Rice
BA110052	**T 2341 (4) H9**	Baodun Phase 1	3830±30	Rice
BA111218	**T 3312 (7)**	Baodun Phase 1	3995±20	Wood
BA111219	**T 3411 (7) H18**	Baodun Phase 1	3735±20	Rice
BA111215	**T 3411 (7) H17**	Baodun Phase 1	3840±25	Rice
BA110055	**T 2426 (4)**	Baodun Phase 2	3990±30	Rice
BA110057	**T 2431 (3) G1**	Baodun Phase 2	4000±30	Rice
BA111220	**T 3211 (6) H10**	Baodun Phase 2	3795±25	Rice
BA111216	**T 3209 (5c) H8**	Baodun Phase 3	3795±25	Rice
BA111217	**T 3211 (6)**	Baodun Phase 3	3885±25	Rice

Table 7.4 (Continued)				
BA110056	**T 2431 (3)**	Han	2150±25	Rice
BA110053	**T 2426 (3)**	Han	2015±30	Rice
BA110054	**T 2426 (3)**	Han	3565±25	Rice

These dates clearly situated Baodun period activity at the site as taking place between 2700-2000 BC. Examination of the dates makes it immediately apparent that the three phases represented by pottery chronology are not reflected in the distribution of archaeobotanical material across the site and that substantial mixing of deposits occurred at the site (Figure 7.2). There are many reasons why this may be this case: It is possible that burrowing by rodents and insects could have moved later archaeobotanical material down. In addition, when clay or earth was extracted from the ground to build houses or to dig trenches or pits, it is likely that earlier material made its way to what was the surface at the time. It is clear from these dates, however, that rice was continuously used throughout the occupation of the site. Despite there being much perturbation of the site, the radiocarbon dates show that the occupation seems to correspond roughly to two different phases as predicted by Jiang.

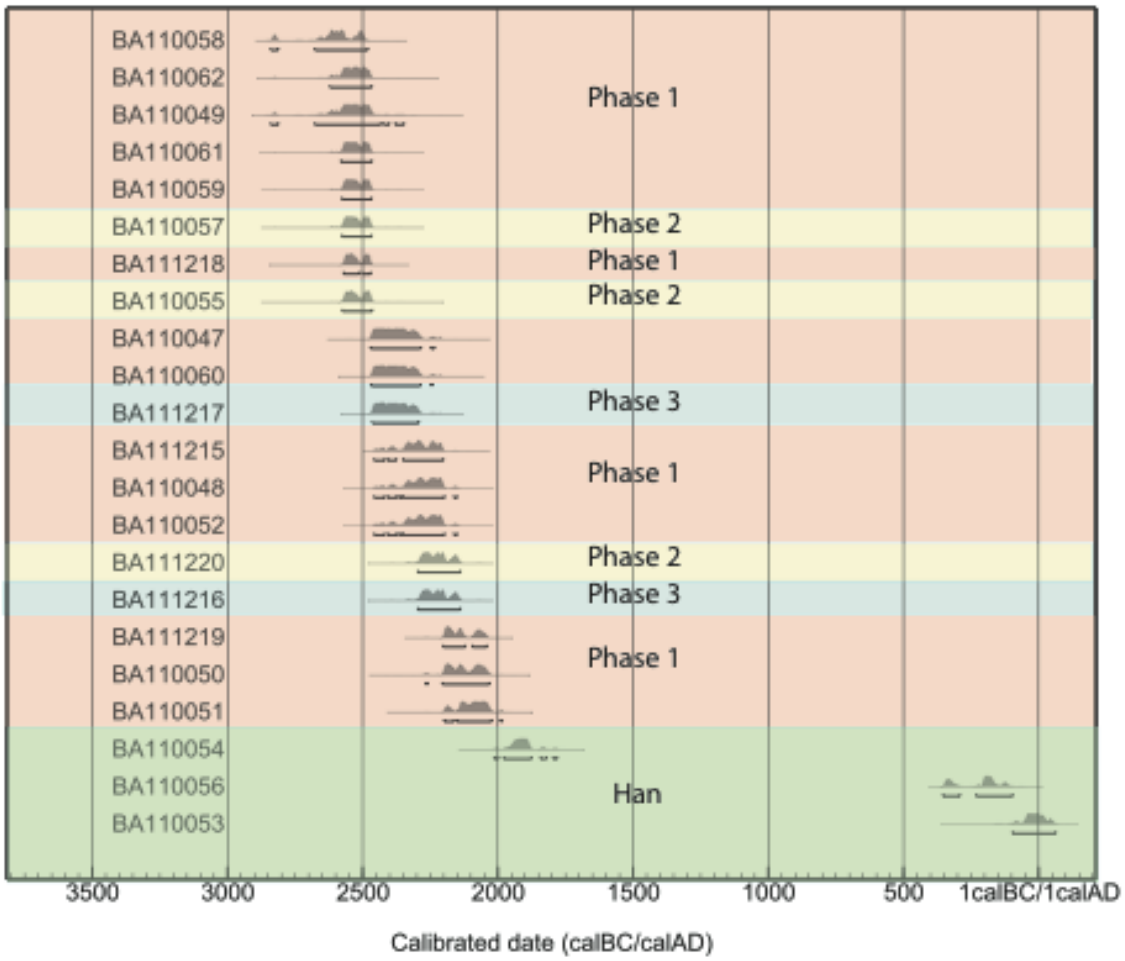

Figure 7.2 Calibrated Radiocarbon Dates for the four phases represented at the site of Baodun showing the two-sigma probability intercepts with the calibration curve (from IntCal 2009). Dates are in order of uncalibrated radiocarbon determination (see Table 7.3 for uncalibrated dates).

7.2 Changes in Subsistence Patterns on the Chengdu Plain

A number of species of edible plants were present in the Baodun assemblages from the Chengdu Plain including rice, foxtail millet, broomcorn millet, Job's tears, a small seeded species of vetch (*Vicia* sp.) and wild *Vigna*.

7.2.1 Rice

An analysis of the ubiquity (Figure 7.4) and of overall proportions (Figure 7.3) of domesticates indicates that rice was by far the most important domesticate on the Chengdu Plain, followed by foxtail millet.

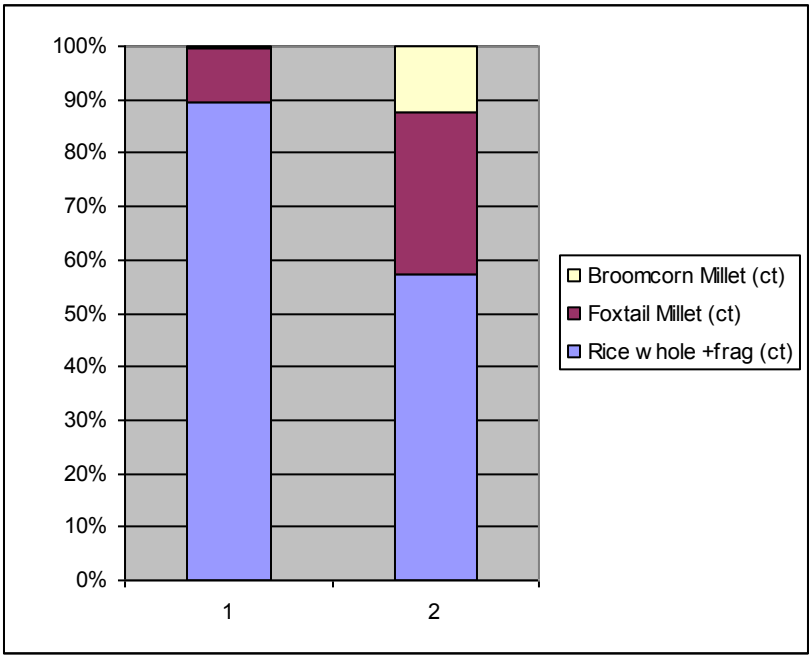

Figure 7.3 Proportions of cereal crops at Baodun based on total counts

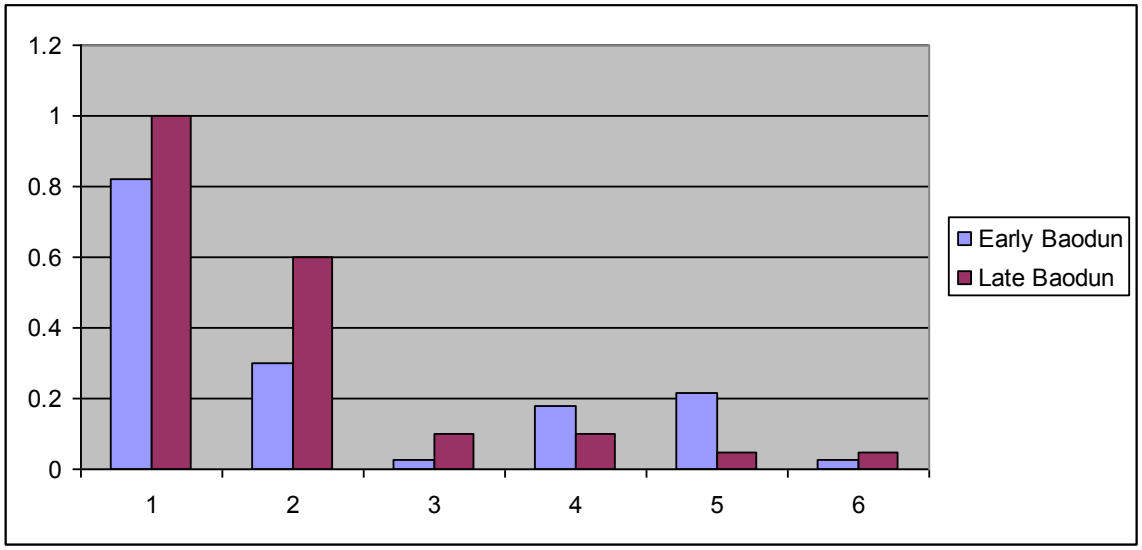

Figure 7.4 Ubiquity of Main food crops during the Baodun period on the Chengdu Plain 1) Rice, 2) Foxtail millet, 3) Broomcorn millet, 4) *Vicia* sp. , 5) Job's tears, 6) *Vigna* sp.

Table 7.5 Counts of main domesticates on the Chengdu Plain during the Baodun period

Crop	Baodun Early	Baodun Late
Rice	930	597
Foxtail Millet	104	319
Broomcorn Millet	2	128

7.2.1a Domesticated or non-domesticated assemblage: Rice spikelets

An examination of rice spikelet bases permits determination of whether or not an assemblage of rice is primarily from domesticated plants. Although it is expected that the type of rice agriculture that spread to the Chengdu Plain consisted of rice that had long been domesticated, this must be demonstrated. In wild rice populations, once maturity is reached, the spikelet base shatters or detaches itself allowing the plant to disperse its seeds. Reaping and replanting of

seeds by humans selects for a non-shattering mutation. In wild populations, large numbers of immature spikelet bases are expected to be harvested. I studied the morphology of 702 rice spikelets removed from the 0.5 and 0.25mm fractions at Baodun. Spikelet bases were assigned to the domesticated, wild, immature or unidentifiable categories based on Fuller et al. (2009).

We carried out an analysis of rice spikelets on a phase by phase basis at Baodun, however did not see any patterning. In addition, given that considerable mixing took place at the site we decided to combine all samples for analysis. When all three phases of the Baodun samples are combined, a majority (55%) of spikelet bases were domesticated in morphology. Only 11 % have wild morphology and 1 % are immature (Figure 7.5).

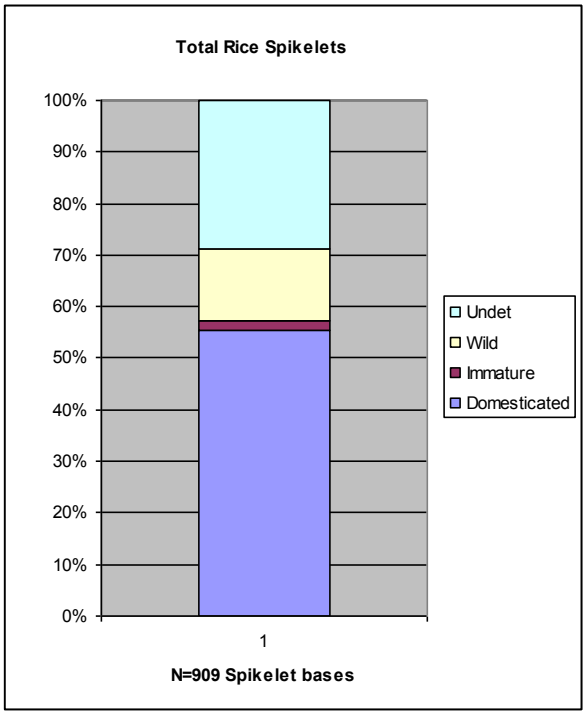

Figure 7.5 Rice spikelets at Baodun: All phases combined (n=702)

These patterns reflect a domesticated population, approaching the 69% of domesticated spikelets, 25% of wild spikelets and less than 1% of immature spikelets that have been indentified in the only published evidence of rice spikelet bases from a context that is understood to be a fully domesticated population (the site of Liangzhu c. 2200 BC) (Fuller, et al. 2009). Unfortunately, we were not able to assign a category to 31% of the total number of spikelets. Similarly, for wheat, it is expected that domesticated populations retain an average of 10% of naturally shattering spikelet bases (Willcox 1999), putting the proportion of wild spikelet bases from Baodun within the range of a domesticated population. These numbers are consistent even if examined on a phase by phase basis. This is expected, as by this point rice had already undergone morphological domestication in other regions of China.

An analysis of rice spikelets from the Baodun layers at the site of Zhonghai revealed a similar pattern, although here the proportion of wild spikelets was considerably higher and formed roughly 30% of the assemblage. The reasons for this are unclear.

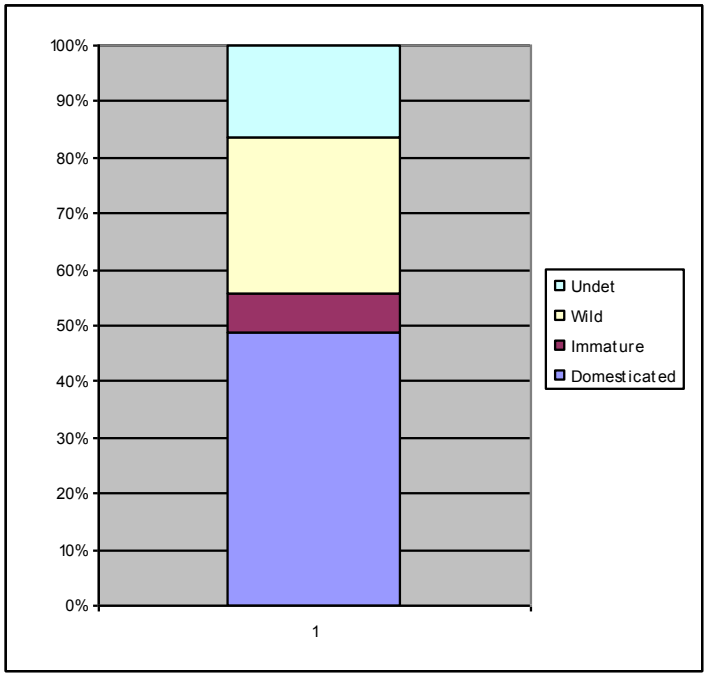

Figure 7.6 Rice spikelets examined from the site of Zhonghai (Baodun layers) (=2797)

As rice agriculture moved, it is possible that the rice may have come into contact with local stands of wild rice and exchanged genetic material. If wild stands of rice were present around the site of Baodun, the very low proportion of wild and immature spikelet bases indicate that farmers likely practiced weed management and segregation to prevent these stands from interfering with the productivity of their fields. Segregation from wild stands of rice may also have been achieved by the fact that these plants had already undergone another aspect of domestication, the switch from out-crossing to self pollination as a result of differences in timing of maturity and placement of sexually reproductive parts (Fuller, Qin et al. 2008a; Oka and Morishima 1967). The very low number of immature spikelets further indicates that the rice at Baodun ripened together allowing farmers to reap their harvest once grains had achieved full size. It appears that the population of rice cultivated by farmers at Baodun was already highly productive.

7.2.1b Rice morphometrics: Temperate or tropical japonica rice?

Fuller (2012) has argued that there is a relationship between rice morphometrics and environments. In particular, shorter grains tend to be found at high latitudes or high altitudes, and are typical for temperate japonica, whereas tropical japonica tends to have longer grains. An analysis of growing degree days (see Chapter 4) showed that the Chengdu Plain, the Three Gorges and other parts of the Yunnan-Guizhou Plateau was characterized by cooler temperatures than the middle Yangzi and similar temperatures to Shanxi, Henan and Gansu. As discussed in chapter 5, Fuller suggests that a temperate type of *O. japonica* may have differentiated around the Late Majiabang-Songze-Liangzhu (c. 5000-2250 cal BC) based on evidence from the Lower Yangzi. In addition, Fuller and Castillo (In Prep) argue that the short grained morphology associated with temperate japonica begins to appear at sites such as Nanjiaokou and middle Yangshao sites in Northern China, leading one to believe that the spread of rice agriculture northwards may have been facilitated by the development of temperate varieties of *O. japonica*.

I carried out an analysis of rice morphometrics to determine if the varieties of rice grown in the Chengdu Plain belonged to a temperate or tropical variety of *O. japonica*.

There has been some discussion of the meaning of rice morphometrics, and in initial studies, it was believed that these could help separate between *O. indica* and *O. japonica* varieties of rice in China (Hunan Sheng Wenwu Kaogu Yanjiusuo 2006; Zhejiang Sheng Wenwu Kaogu Yanjiusuo 2003). Genetic evidence along with the timing of rice domestication in India has shown that it is unlikely that *O. indica* varieties of rice made it to China at this point in time. L/W greater than 2.5 was taken to indicate the presence of *O.indica*, whereas Japonica should be less than 2.3 (Zheng 2004). For instance, at Kuahuqiao it has been argued that that grain measurements

indicate *indica* rice (Zheng et al. 2004b; Zhejiang Provincial Institute of Archaeology 2004). Fuller points out that ratios of immature rice can overlap with both wild rice and *indica* and argues that lower Yangzi rices including the rice grains from Kuahuqiao, Hemudu, and Majiabang are immature (Fuller, Qin, et al. 2008). Fuller argues that the domestication process should lead from a thin *O. rufipogon* towards a short grained and plump *O. japonica* (Fuller, Qin, et al. 2008) and that in more Northern cooler climates there should be a tendency towards shorter fatter grains. As has already been shown that the population of rice on the Chengdu Plain was fully domesticated, I was not concerned about the presence of wild rices interfering with measurements.

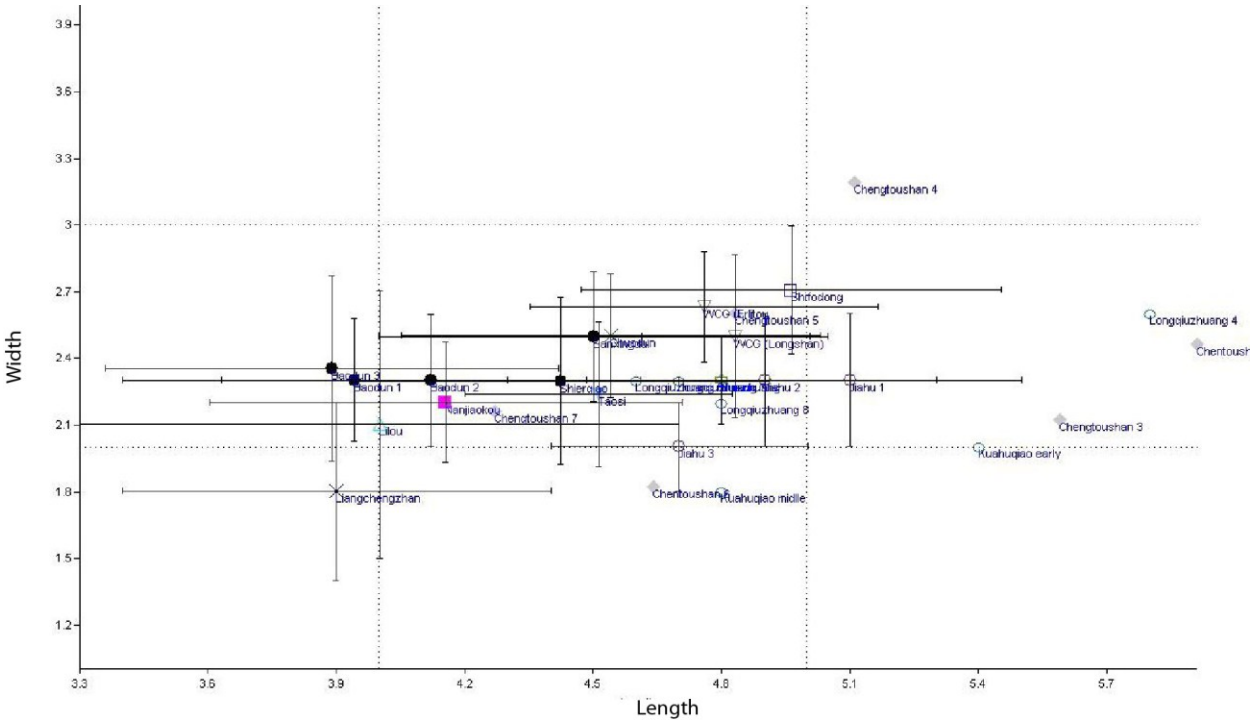

Figure 7.7 Scatterplot of rice measurements from the Chengdu Plain. Note that rice grains from Baodun settlements are extremely short and fat. Black dots represent the samples from the Chengdu Plain.

In order to determine if Baodun rices belonged to temperate or tropical varieties of japonica, we compared L: W ratios to those from a number of published sites using scatter plots and boxplots (Figure 7.7 and 7.8). A total of 488 rice grains from sites dating to all occupations of the Baodun as well as later Bronze Age sites were measured for this analysis. Although there is some variation throughout time, Baodun appears to have shorter and fatter grains than the majority of early period sites, and its measurements are closest to those from to a Yangshao site in Henan Province, Nanjiaokou (4400-3000 BC)[5]. The short and squat nature of the rice grains from the Chengdu Plain leads one to believe that one is dealing with a temperate and perhaps not a tropical japonica. It is possible that the development of a temperate japonica might have been instrumental in moving rice agriculture into these areas of slightly cooler climate. The fact that temperate varieties of *O. japonica* appear only after 4000 BC may have impacted the timing of the spread of agriculture to southwest China.

[5] During later phases of occupation on the Chengdu Plain, measurements change somewhat. Sanxingdui period samples are very close to Chuodun (4000 BC). Shierqiao period samples closer to Taosi (2000-1300 BC) and grains are longer than in the Sanxingdui period, although it is possible that this may be due to a larger sample size and hence more immature grains during this period of time.

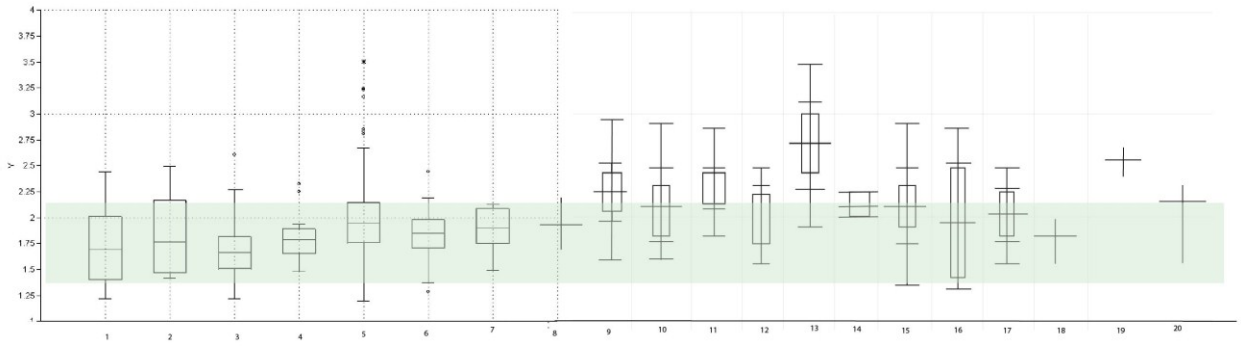

Figure 7.8 Boxplots of L:W Ratio of rice grains from reported sites

1) Baodun 1; 2) Baodun 2; 3) Baodun 3; 4) Sanxingdui; 5) Shi'erqiao; 6) Shifodong 7) Nanjiaokou; 8) Chuodun; 9) Jiahu 1; 10) Jiahu 2; 11) Jiahu 3; 12)Yuezhuang; 13) Kuahuqiao L6; Longqiuzhuang 6 and 4; 14) Nanjiaokou (Liu Li), 15) Liangchengzhan; 16) Lilou; 17)Huizui; 18)Dazuizi; 19) Bashidang; 20) Chengtoushan

7.2.2 Foxtail millet

The amounts of foxtail millet were also unearthed from the archaeobotanical assemblages on the Chengdu plain were small, but it was nonetheless the second most ubiquitous crop and had the second highest proportion. It is possible that the lower numbers of foxtail millet may partially be due to different patterns of preservation. Experimental studies have shown that because of their higher surface area, smaller seeds such as millets may not survive the carbonization process as well as larger seeds like rice (Castillo 2011; d'Andrea and Catherine 2008; Markel and Rosch 2007; Wright In Prep). Lower density could also be due to difficulty recognizing *Setaria italica* fragments and distinguishing them from other panicoid weeds. Foxtail millet could have been cultivated either alongside rice agriculture during the summer or been planted in the fall as a late season or as a fallback crop in years of poor yield. Further work on available growing degree

days during the winter months on the Chengdu Plain could help determine the season of its sowing.

7.2.3 Broomcorn millet

Small numbers of broomcorn millet were also unearthed from sites dating to the Baodun period. An increase in their proportions as well as their ubiquity is apparent when comparing early and late Baodun (Table 7.4).

7.2.4 Job's tear

Job's tear (*Coix sp.*) was recovered in the form of fragmentary pieces of involucral bract as well as charred seeds. Identification was made on the basis of comparison to modern reference material I collected. The outer surface of the bract was characterized by a translucent and lustrous outer surface on both carbonized and uncarbonized specimens which shows a characteristic cleaving pattern. This surface has minute cell structuring. The interior surface of the involucre shows clear fibrous and vascular bundles, which are also visible in cross section and which correspond closely to the specimens described by Jiang et al (2008)[6]. Only two species of *Coix* are naturally distributed in China: the annual cultivated *Coix lacryma-jobi* and the perennial *Coix acquatica* (Chen and Phillips 2006). Because of the very fragmentary nature

[6] In addition to Job's tears we also unearthed a large amount of *Hacklecloa* involucral bract. Initially, these appeared very similar to the specimens of *Coix*. Finds of several intact specimens of *Hackelocloa* allowed us to separate them on the basis of the following characteristics. The surface of the involucral bract of *Hackelocloa* is either smooth or has a reticulately wrinkled surface pattern. More complete specimens have a hard triangular shaped apex that is another important distinctive characteristic (see Appendix D). While the specimens with patterned surface pattern are readily distinguishable from *Coix*, those with a smooth surface run the possibility of being confused with the latter. Examining the interior surface patterning of the two allows for the most reliable distinction between the two genera. The interior surface of the involucral bract of *Hacklecloa* shows distinctive rows of ladder-like patterns (see Appendix D). The interior surface of *Coix* on the other hand is generally thicker and has the clear fibrous bundles described above (see Appendix D) *Hackelocloa* has been reported as a weed of cultivation.

of our specimens we were not able to distinguish between the two. Although only three caryopses were recovered from the sites of Baodun and Zhonghai, a large number and high ubiquity of involucral bracts was present, making it possible that these *Coix* sp. may have been gathered or cultivated as a food source by the inhabitants of the Baodun culture.

Job's tears has a rich history of exploitation, and starch-rich varieties have been used as both crops or medicinal plants through East and Southeast Asia, particularly in Northeastern India (Arora 1977; Grubben and Partohardjono 1996; Roder 2006). The involucral bract is also used for making beads. The fact that the involucral bracts of all specimens uncovered at Baodun were recovered in a highly fragmentary form suggests that they may have been exploited as a food source rather than as jewelry. A number of intact spikelet pairs from the weed *Hackelochloa* were recovered from the assemblage. This suggests that should these have entered the assemblage as a weed, one would expect to find at least a few intact specimens. The wild perennial *Coix acquatica* has been observed as a weed of aquatic environments and we cannot eliminate the possibility that these were in fact weeds of rice paddy agriculture (Weisskopf, et al. 2010).

The history of domestication of Job's tears is poorly documented. Some scholars speculate that it may have been domesticated somewhere in either Eastern Asia or the Indian subcontinent (Fuller, Qin, et al. 2008a; Jain and Banerjee 1974; Simoons 1991). Today in India, the cultivation of this crop is largely limited to the mountainous regions of the Himalayas. Watt (1908) has hypothesized that populations moving across the Himalayas may have played an important role in the distribution of this crop. Only a handful of archeological finds have been reported. A

single specimen was unearthed from the site of Hemudu (c. 5000–4500 cal. BC) (Zhejiang Sheng Wenwu Kaogu Yanjiusuo 2003), however it is unclear whether or not this specimen represents a modern intrusion. Starch from Job's tears was reported at the Xishan site (c. 1046–256 BC) (Ge, et al. 2010). Much later finds have been unearthed at the Sampula Cemetery in Xinjiang (0 AD) (Jiang, et al. 2008). A number of seeds were also reported from a set of Eastern Han (25-220 AD) dynasty tombs in Xi'an (Zhao 2010e) as well as in Luoyang (Yu 1977).

Historical mentions of Job's tears date to the Han dynasty, where it is reported to have been brought to Northern China from the kingdom of Nanyue in Southern China by the general Ma Yuan (Simoons 1991; Smith 1969). Large quantities of *Coix* were unearthed at a Harappan site of Kuntasi in India (c. 2200-1700 BC), where it was presumably made into beads (Kajale 1996). Closer to China, Job's tear has also been found in layers of the site of Mebrak in Nepal dating to c. 400-100 cal BC. In Southeast Asia, Job's tear has been uncovered from sites in the Khao Wong Prachan valley in Central Thailand (Weber, et al. 2010). The Job's tears uncovered at Baodun (c. 2700-2000 BC) are thus the second oldest archaeologically discovered and form an important lynchpin in our understanding of when the exploitation of this crop began.

The single Job's tear caryopses unearthed from Baodun and Zhonghai are, however, small (3mm in length and width). Domesticated Job's tear used for the food market, measures on average 1-2 mm larger than the example unearthed from Baodun. After being carbonized at 300 degrees Fahrenheit for 30 minutes in a muffle furnace, a collection of 75 Job's tears was distorted beyond recognition and was impossible to measure. Charring in a muffle furnace at the same temperature for 15 minutes, yielded only 20 % of fully carbonized caryopsis, however these became extremely puffed and experienced a huge increase in size (Figure 7.9).

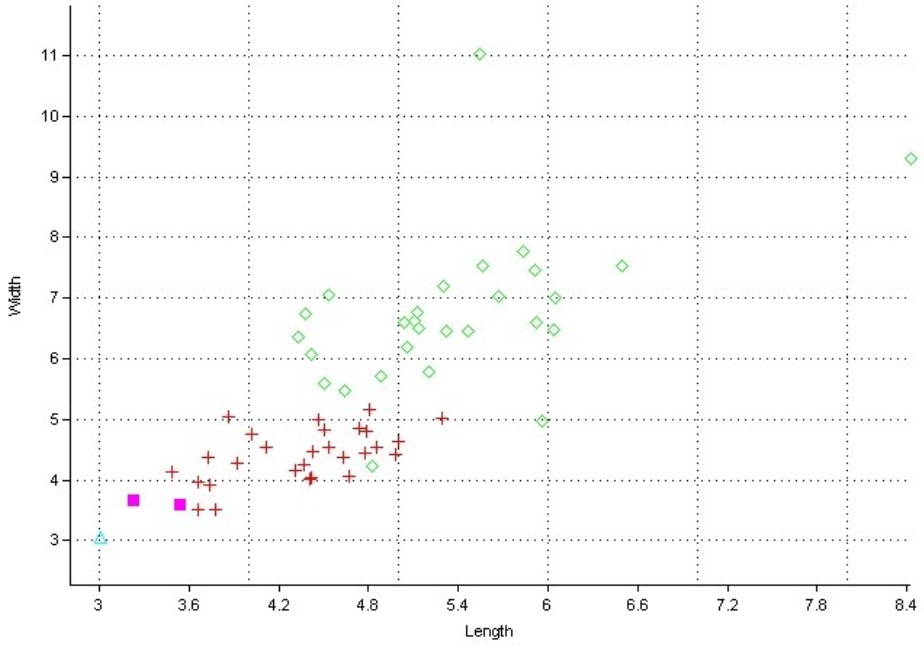

Figure 7.9 Job's tears carbonization experiment. After being carbonized at 300 degrees Fahrenheit for 30 minutes in a muffle furnace, a collection of 75 Job's tears was distorted beyond recognition and impossible to measure. Charring in a muffle furnace at the same temperature for 15 minutes yielded only 20% fully carbonized caryopses, although these had become extremely puffed and experienced a huge increase in size. Job's tears may thus be biased against preservation by carbonization. Archaeological specimen from Baodun (Late Baodun)= blue triange; Archaeological specimens from Zhonghai (late Baodun) = pink square; uncarbonized domesticated Job's tears = red cross; carbonized domesticated Job's tears (these are the same caryopses as those measured in red) = green circles.

Job's tears may thus not preserve well due to carbonization, eliminating it from the archaeological record in many cases. When plotted relative to experimentally charred and

uncharred specimens, the specimens of Job's tears from Baodun and Zhonghai were clearly distinct in size. It is likely, therefore, that the example unearthed was a wild variety, however it is also possible that it is immature. More work on changes in size of Job's tear as maturation occurs is necessary. The presence of wild Job's tears at the site of Baodun, yields some fascinating possibilities about the origins of this crop's domestication.

7.2.5 Pulses

Large numbers of a small round vetch (*Vicia* sp.) were present in the assemblage from sites of the Baodun period. The *Vicia* sp. present in our sample was small seeded (1.5 mm average diameter) and spherical. Thirteen species of *Vicia* are endemic to China (Bao and Turland 2010), however large overlaps in their morphological characteristics make them difficult to identify to species. The specimens unearthed at Baodun are characterized by a large range of sizes, pointing either to the existence of several different species or different stages of maturity.

The use of different species of *Vicia* as a food staple in other areas of the world is well documented both archaeologically and historically. Bitter vetch (*Vicia ervilia*) has been documented in archaeological sites as early as the 7^{th}-6^{th} millennium BC in Turkey. There are also reports of it occurring in archaeological sites in the Uttar Pradesh region of Northern India (Pokharia 2008), and it was well known as a fallback food in Europe in historical times (Zohary and Hopf 2000). Today in Sichuan Province, the leaves of Chinese species of vetches are commonly used in both soups and stir fry. The seeds of *V. sativa* are reported as being collected in times of famine (Hu 2005). *Vicia* is, however, also a common ground cover in dryland fields, and it grows extensively in disturbed areas around sites (Li 1998; Wang 1990). It is possible that

its introduction into the site may also have been as a weed. If so this should be considered a weed of dry-land agriculture and not of the paddies in which rice was grown. I argue, however, that it is unlikely that *Vicia* sp. entered the assemblage as a weed. Generally weeds are only harvested along with a crop when they grow to a similar height as the crop itself. Therefore in dryland fields such as in fields of foxtail or broomcorn millet one would only expect to harvest weeds that grow to the same height as the crops. As *Vicia* is a ground cover, it is unlikely that it would have been accidentally harvested, giving support to the idea that it was grown or collected as a food resource.

Species of *Vigna* can be identified on the basis of overall shape, hilum and plumule position (Fuller and Harvey 2006; Crawford and Lee 2003). Two poorly preserved cotyledons of *Vigna* sp. were found in early layers at the Baodun site. Fourteen species of *Vigna* are native to China. Although one specimen was too fragmentary to attempt an identification, only adzuki bean (*V. angularis*) corresponded to this specimen in terms of overall shape and plumule length. Adzuki bean can be distinguished from mung bean (V. *radiata*) on the basis of plumule length. While Adzuki bean has a short plumule, less than 1/3 of the total length of the specimen, mung bean has a long plumule. 5 specimens of *Vigna* sp. were also unearthed from the site of Zhonghai, however only two of these were well preserved enough to attempt an identification. On the two better preserved specimens, the presence of a short plumule also led us to believe that we were dealing with a potentially wild variety of *V. angularis*. The small size of these cotyledons (< 3mm length and < than 2.4 in width) fits into the size range for wild *V. angularis*, known from Chulmun and Mumum sites in Korea (See discussion in chapter 6). The general poor state of preservation of these specimens, makes these identifications difficult to confirm.

7.2.6 Fruits and Condiments

A number of other economically important species were unearthed from sites in the Chengdu Plain (Table 7.6). These include Beefsteak plant (*Perilla sp.)*. Beefsteak plant is used widely in Japan and Korea and to a limited extent in China for its aromatic leaves, oil and seeds. Seeds of beefsteak plant are very common in early Jomon period archaeological sites in Japan (Crawford 1992, 2006) as well as throughout northern China (Zhao 2010a; Zhao and Fang 2007; Zhao and Xu 2004). Finds have also been unearthed at the Middle Yangzi site Chengtoushan (Nasu, et al. 2011). Other species of mint that appear to be closest to members of the genus *Stachys* are also present. There are 18 species of the genus *Stachys* in China, a number of which have edible rhizomes. The most common of these is *Stachys sieboldii* (Wu, et al. 1994), which is thought to have been domesticated in northern China for its edible rhizomes (Chang 1970; Simoons 1991).

Fruits are an important component of any diet, however in many instances are under-represented in archaeological sites as seeds are often discarded off site. Two different species of fruit were unearthed from Baodun. A single seed of wild *Cratageus* sp. or Hawthorn was unearthed in Ashpit 5 at Baodun and 8 fragmentary pieces of hawthorn were unearthed from Zhonghai. *Cratageus* sp. has a long history of consumption in China, however, to date has only been described in sites from Northern China (Fuller and Zhang 2007; Simoons 1991). These specimens are small (3mm long) compared to modern domesticated *Cratageus* and were likely a wild variety. In addition, 3 charred specimens of *Sambucus* sp. were also uncovered from the late Baodun ashpit at Zhonghai.

A few fragments of peach (*Amygdalus persica*) endocarp were discovered in late Baodun period sites. In Southern China, wild peach has been found at numerous sites in Zhejiang province, including at the site of Tianluoshan (Beijing Daxue Kaogu Xue Yanjiu Zhongxin and Zhejiang Sheng Kaogu Yanjiusuo 2011). Further south, wild peach has also been found at the site of Haimenkou (Personal Communication: Jin Hetian 2012). In Northern China, the earliest finds of peach first appear during the Yangshao period at the Yangcun site (Fuller and Zhang 2007). It is unclear when management of peach trees began in China and when domestication of these species occurred, however, Song (2011) argues that the spread of these species outside of their area of natural occurrence can provide evidence for their cultivation. For instance, the earliest evidence for the spread of peach to Northwest India dates to 1900-1700 BC, accompanied by a host of Chinese crops, indicating that they may have already been cultivated by this date. She suggests that the cultivation of fruit crops such as jujube and peach were underway by the late Longshan period (c. 2000 BC). Hosoya et al. (2010) have argued that in addition to the fruit, the kernels (seed) of peaches were also consumed by early habitants of the lower Yangzi. Peach kernels are still used in Chinese cuisine today and are referred to as bitter almonds. Boiling, steaming and fermentation are required to remove the high concentration of prussic acid present in these kernels (Hosoya, et al. 2010). The fact that no whole endocarp was uncovered and all endocarps were recovered in a highly fragmentary form also suggests that the inhabitants of the Baodun culture may have also processed and consumed peach kernels.

Table 7.6 Total counts of Fruit present in the Baodun period

Fruits	Baodun Early	Baodun Late
Cratageus sp.	1	8
Sambucus sp.	1	3
Amygdalus persica sp.	0	38

7.3 Microbotanical Analysis at the Site of Baodun:

In addition to samples relating to macrobotanical remains, samples for phytoliths and starch grains were also recovered and were analyzed by Chen Tao at the Chinese Academy of Science. A column sample was taken from the wall of unit T3211 and one sample each was taken from ashpits H10 and H12. The column sample from T 3211 was removed from the west wall and 8 clear stratigraphic units were visible in profile. Samples were collected according to natural stratigraphic breaks. Layer 1 was a disturbance layer and layer 2 dated to the Song Dynasty. Layers 3-5 dated to the Han dynasty. Layer 6 was dated to phase 2 of the Baodun culture and Layer 7 to phase 1 and appeared to be the floors of housing structures. Both of these features were cut into sterile earth in layer 8.

Large numbers of fan shaped phytoliths from rice stalks and dumbbell phytoliths from rice glumes were extracted from the layers relating to the Baodun period. In addition to rice phytoliths, a small number of phytoliths derived from the lemma of a panicoid grass were found in the samples; these were too poorly preserved to determine if they belonged to *Setaria italica*. These fragments only appear in layers 6 and 7, possibly relating to the concentration of these phytoliths in building features. Weed flora was unfortunately not analyzed in these samples, however, the analysts communicated that he did find phytoliths from the Cyperaceae family

(Chen Tao: Personal Communication 2012). The patterns revealed in this microbotanical analysis are largely consistent with what is known from macrobotanical remains.

7.4 Agricultural strategies on the Chengdu Plain during the Baodun period

The patterns found at sites of the Baodun culture suggest that from its earliest occupation, the spread of agriculture to the Sichuan Basin involved a whole scale movement of already domesticated rice as well as foxtail millet. The sudden appearance of Baodun culture sites on the Chengdu Plain together with a fully formed crop repertoire, ceramics as well as what appears to be the ability to harness large numbers of people to build walls, suggests that the Baodun culture may have been the result of migration of agriculturalists into the plain from other some location further to the east. The presence of walls as well as the similarity in some ceramics vessels to sites of the Qujialing and Shijiahe periods in the Middle Yangzi, suggests that a movement from this area. The apparent absence of prior occupation in the plain supports this hypothesis, as no clear trajectory from hunting and gathering to a gradual adoption of agriculture is visible in the archaeological record. Given that hunter-gatherer populations occupied most environments in prehistory, it is highly likely, however, that hunter-gatherer populations occupied the plain, but they may have been highly mobile with low population densities and as a result left little evidence of their existence. The kind of interactions moving agriculturalists had with local foragers is a fascinating question that we currently do not have enough evidence to investigate.

The review of the linguistic evidence opens a variety of possibilities as to the potential language groups that could have been involved in this spread. These include Sino-Tibetan, Hmong-Mien

and Austro-Asiatic. The language spoken by the inhabitants of Baodun is likely to have been close to the languages spoken by inhabitants of the middle Yangzi, whatever these may have been. Following the arrival of the inhabitants of the Baodun culture, the Sichuan basin became a dynamic zone of exchange. Although the later Sanxingdui and Jinsha cultures of the plain show clear ties to Baodun, during later periods of times, namely the Warring States, this area again showed evidence of influence from the Middle Yangzi, namely with connections to the State of Chu (Sage 1992). It is very possible that language phyla may have undergone considerable replacement during this period of time and that the languages originally spoken by the populations of the Chengdu Plain became extinct as their culture was eventually subsumed into that of imperial China c. 221 BC (Sage 1992).

Unlike the earliest evidence for the spread of agriculture to the Three Gorges, in the Chengdu Plain, subsistence was heavily based on rice and not on millets. In addition to rice, foxtail and broomcorn millet, and a number of wild crops not known to sites in surrounding regions appear in the assemblages at Baodun: these include the small seeded species of vetch, job's tears and as well as wild species of *Vigna*. This shows that in addition to crops that were imported, new additions that were probably local to the Chengdu Plain were added to the diet. Was knowledge of these crops transmitted by local hunter-gatherer populations or did moving agriculturalists experiment with new plants in this new ecological zone?

7.5 Spread of Rice and Foxtail Millet Agriculture beyond the Sichuan Basin: Yunnan, Guizhou, SE Asia

The finds from Baodun represent the earliest evidence for the spread to Southwest China. From here, rice agriculture appears to have spread southward to the Yunnan Guizhou Plateau. How this spread occurred and what populations were involved in the movement of these crops is unknown. Unlike the Sichuan basin, where no evidence of early populations have been unearthed, a number of sites dating to roughly 3000 BC have been reported from in the Yunnan-Guizhou highlands, which share some cultural connections to sites of highland western Sichuan. Yao (2010) divides these into early (3000-1800 BC) and late (1800-1000 BC) Neolithic sites. Most of the early period sites are reported from Dali prefecture in Northwestern Yunnan.

A number of sites in the upper Jinsha river valley, including the sites of Getengcun and Daxingzhen (Yao 2010), share close similarities to those of later western Sichuan, as reflected in the presence of double handed jars known from the cist tomb culture that later occupies this entire region. Two of the earliest sites in the region are Baiyangcun (2300-1700 BC) and Xinguang (2900-2000 BC), which are located in the middle Jinsha river valley, however, these are associated with a very different type of incised and impressed pottery. This includes the sites of Caiyuanzi, Mopandi, and the early phases of occupation at the site of Haimenkou. The use of impressed/incised wear appears to continue to the middle and lower Lancang valley at the sites of Shifodong and Nanbiqiao (Zhao 2010d). The lower Jinsha river valley is characterized by sites containing gray amphora, including the sites of Zhaxinchang, Maguang, Jigongshan and Wujiadaping. A different complex of corded ware is present in the Lake Jili Basin at the sites of Haidong, Yangshan, Xiaohedong, Dahuashi, Chuankouba, Muchengma and Yingpanshan, most of which are either shellmound or cave sites (Yao 2010).

In highland Guizhou, a number of important caves showing occupation ranging from the late Pleistocene to the early Holocene have been investigated. These include the caves of Maomao Dong in Xingyi, Guanyingdong in Lingxi, Dadong in Pangxian, Pudingchan cave, Guanying cave in Anlong, and Tongzi Ma'an and Xiaohui cave in Shuicheng (Wu 2010). Radiocarbon dates at the Pudingchan cave in dates of 7700-7000 cal BC (Wang 2006; Zhang 1998). The nature of the subsistence practices of the hunter-gatherers occupying these sites has been woefully under-investigated. Sites are also known from later periods of time, including the group of sites at Laopodi along the Sanfen River in northwestern Guizhou, in Weining county in the Lingxi area. Near the Yunnan border, groups of sites at Zhongshui, Jigongshan, Hongyingpan and Yingziyun have also been unearthed. This culture's center appears to be in the Zhaotong region of Yunnan. Sites in this area show close connections to those of the Liangshan area in Sichuan and cultures in neighboring Yunnan. Some even argue that at the site of Jigongshan shares cultural connections with the Sanxingdui culture (Wu 2010).Whether these represent foragers or farmers, the people inhabiting this region clearly had far reaching connections (Wu 2010).

In the Lingnan area, a large number of sites have been found along the southern valley of the Beipanjiang, bordering Guangxi. Sites in the Lingnan area show close cultural connections to sites in Guangxi with large numbers of flaked stone tools and low-fired pottery. In addition, a number of sites have been identified in the northwestern corner of Guizhou, near the borders of Sichuan and Chongqing, however, no details on these sites are available. Excavations carried out at these sites may show that they contain evidence for documenting how agriculture spread into the Sichuan Basin.

7.5.1 Early archaeobotany in Yunnan and Guizhou

Only a few archaeobotanical finds have been published from Yunnan and Guizhou as a whole, and fewer still have been directly dated. In Yunnan Province, the earliest evidence for rice has been found in the Neolithic phases of the Haidong site of the Shizhaishan culture, which dates to approximately 2500 BC (Xiao 2001; Zhang and Hung 2010). It is unclear, however, what materials were used for dating this site and what layers the finds of rice came from. Rice husks have also been found at the sites of Baiyangcun in Bingchuan county (c. 2300-2000 cal BC), however the rice grains from this site were not directly dated (Yunnan 1981; Zhang and Hung 2010). Slightly later, rice has also been discovered at the site of Yongping Xinguang, which dates to approximately 2050-1750 cal BC, according to dates carried out on sediment (Yunnan et al. 2002). A few remains of carbonized rice were uncovered in a ditch. Later finds of rice grains are known from the site of Mopandi in Yongren County (c.1400 BC) (Zhao 2003b). Similarly dated finds of rice come from the site of Dadunzi in Yuanmou (Yunnan 1977) (Table 7.7). Much further south, at the site of Shifodong, systematic flotation revealed both rice and foxtail millet. Rice grains at this site were directly dated to 1400 BC (Zhao 2010d). Foxtail millet has also been unearthed, hinting that both of these crops played a role in the spread of agriculture into this region.

Table 7.7 Summary of archaeobotanical work carried out in Yunnan and Guizhou Province

Site	Type of Archaeobotanical Remain	Approximate Date	Material used for Radiocarbon dating
Dongan 9 Neolithic Site at Dianchi	Remains of rice husk found in pottery	?	None
Yongping Xinguang	Rice grains, phytoliths and pollen	c. 2000-1700 cal BC	Bulk sediment sent for radiocarbon dating
Baiyangcun site in Bingchuan	Rice husks and stalks, one wild peach	2466-1962 cal BC	Wood charcoal from house
Mopandi in Yongren	Carbonized rice grains	c. 1400 BC	Dated by association
Dadunzi in Yuanmo	Carbonized rice grains	1730-1270 cal BC	Wood charcoal from House
Gengma Shifodong	Carbonized rice grains	1400 cal BC	Direct date on rice
Haidong		3380-2471 cal BC	Materials unknown

To date, very little archaeobotanical work has been carried out in Guizhou Province. The earliest evidence comes from the Bronze Age site of Jigongshan, where rice appears to have formed an important part of the assemblage (Guizhou et al. 2006). No radiocarbon dating has been carried out at this site. Based on pottery chronology, however, it is said to be contemporaneous with the late Shang, placing it at roughly c. 1300-1500 BC. The late date of these finds has led Zhang and Hung (2010) to hypothesize that the spread of agriculture into southwest China moved from the Sichuan Basin into Southwest China. However, it is probable that the lack of earlier evidence in this region mostly reflects the dearth of archaeological investigation in the province as a whole, making it difficult to understand how agriculture spread. If the finds from the Haidong site have been correctly dated and interpreted, then this indicates that experiments with rice in this region may have begun after rice agriculture moved into the Sichuan Basin.

7.5.2 Adaptations to Highland Environments: Evidence from the Site of Haimenkou in Jianchuan County

Systematic archaeobotanical analysis carried out at the site of Haimenkou (alt. 2200 m) in Jianchuan county Yunnan has greatly improved our understanding of the spread of agriculture onto the Yunnan-Guizhou plateau (Xue 2010). Initially excavated in 1957 and 1978, the Haimenkou site was the subject of a re-excavation in 2008 by the Yunnan Provincial Institute of Archaeology, Dali Prefecture and Jianchuan County Cultural Relics Bureau. Systematic flotation was carried out at the site during this time by a Peking University team.

The site is divided into 3 main phases: The first of these phases is dated to 1600-1100 BC by AMS radiocarbon dating and can be further subdivided into two different sub-phases. The first of these sub-phases is found in layers 8-9 of the site and dates to 1600-1400 BC. No bronze items were found in these layers, which were characterized by black and grey pottery with sandy inclusions. In layers 6-7 (1400-1100 BC), bronze artifacts appear alongside a change in pottery assemblage, color and manufacture (Xue 2010) (Jin Hetian: Personal Communication 2012). Layers dating to 1400 BC contain pottery vessels that share strong similarities with those from the Qijia culture in from Northwestern Gansu (2400-1900 BC). This has led Jin (ND) to hypothesize that the occupants of the Haimenkou site may be migrants of Qijia culture origin. She further hypothesizes that the inhabitants of the Qijia culture may have moved further south due to changing climate. Indeed, following this first phase, the site appears to have been

abandoned for 300-400 years. The site was reoccupied at around 800 BC and iron appears at the site during this period of time.

Large amounts of waterlogged macrobotanical remains were unearthed alongside waterlogged wooden houses (Yunnan Sheng Wenwu Kaogu Yanjiusuo 2009). An analysis of the proportion of crop remains in the assemblage of each period yielded interesting patterns.

Following an analysis of the material carried out by Xue (2010), I decided to re-examine the proportion of crops found at Haimenkou. This was carried out using two different assemblages of crops, one of which included *Chenopodium* sp.while the other did not. Subsistence in the first phase of the site appears to have been primarily reliant on rice, foxtail millet and possibly *Chenopodium*, which the authors argue was exploited as a food source (see discussion in chapter 6, (Xue 2010). In the earliest layers of the site (10 and 9), only rice and foxtail millet appear to have been present in the assemblage. In layer 10, the assemblage is dominated by rice that forms 100% of the total assemblage. In constrast in layer 9, foxtail millet forms over 80% of the assemblage. In these layers, they are associated with weeds derived from a wetland environment, implying that rice at Haimenkou was a lowland variety.

In layer 8, wheat begins to appear in the samples, however it forms only 0.6% of the cultivated crop assemblage and is represented by only 5 specimens. Small amounts of broomcorn millet were also present in the assemblage. During this phase, the proportions of rice and millet even out and rice gains a slight predominance over millet. Starting at around 1400 BC, in layer 7, the proportion of rice in the assemblage decreases dramatically and wheat begins to slowly increase

in the samples from 0.6% to 3.8%. Two caryopsis of barley also appear. Interestingly the proportion of *Chenopodium* increases sharply during this period, as do the proportions of foxtail millet. Layer 6 continues the tendencies of layer 7 and the proportion of rice continues to decline, while *Chenopodium* continues to increase as does wheat. From this point in time onwards, wheat shows a steady increase in the assemblage. Rice all but disappears in later layers of the site, and while foxtail millet is initially retained, it too eventually disappears from the assemblage. In layers 3 and 4 of the site, this trend continues until wheat completely dominates the assemblage (Figure 7.10).

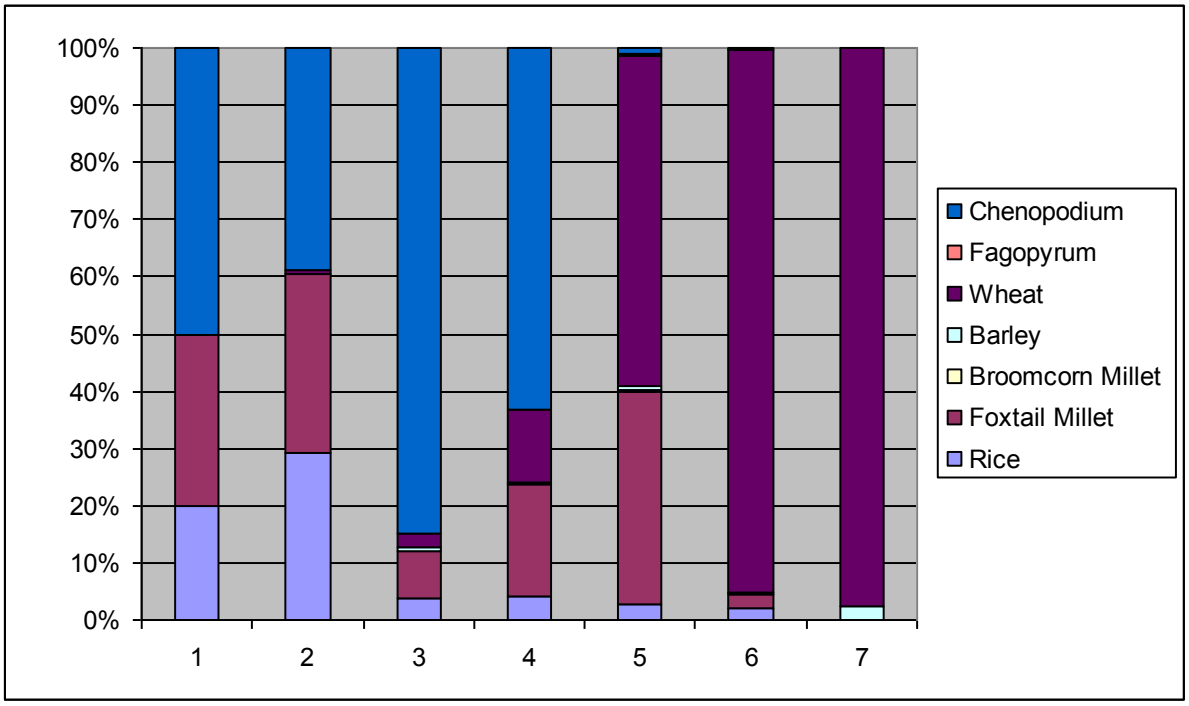

Figure 7.10 Archaeobotanical material unearthed from Haimenkou. 1) layers 9, 2)layer 8, 3) layer 7, 4) layer 6, 5) layer 5, 6) layer 4, 7) layer 3 After analysis carried out by Xue (2010).

The archaeological record at Haimenkou shows some exciting possibilities about how the spread of agriculture into this region may have occurred and how humans adapted their agricultural

system to the challenging environment of the highlands. Much like finds in the Sichuan Basin, both rice and millet are the earliest crops found at the site. Systematic flotation is needed in the earlier sites in this region to determine whether millet agriculture accompanied rice during its spread southwards. The spread of millet agriculture is much less well documented, but this is likely mainly due to sampling strategies. The use of a large mesh size or hand picking favors the recovery of rice. Millets are much smaller and can rarely be seen by the naked eye during the course of an excavation. The underrepresentation of millet in the archaeological record of southwest China may be an artifact of sampling strategies. It is interesting to note that foxtail millet has only been reported from sites where systematic flotation has been carried out, such as the Bronze Age sites of Haimenkou and Shifodong in Yunnan (Xue 2010; Zhao 2010d). In both of these sites foxtail millet occurs alongside rice agriculture. This indicates that foxtail millet cultivation (combined with rice agriculture) formed part of the package of the initial agricultural expansion into the Yunnan-Guizhou plateau. The role played by the introduction of later western domesticates is also important in understanding how humans adapted agricultural systems to this environment and is be discussed in chapter 9.

7.6 Ecological Niche Modeling and the Spread of Rice and Foxtail Millet Agriculture to Southwest China

Domesticated varieties of lowland *O. japonica* rice are desirable staples because of their high yield. However, these crops require large amounts of water for their growth (in a paddy environment), and this can be a limiting factor as to where they can be grown. Although upland varieties exist, my analysis of rice morphometrics and weed flora from the region has

demonstrated that the kind of rice grown in southwest China was likely grown in wetland environments (see discussion on weed flora in chapter 8). In addition, an examination of rice measurements indicates that these varieties of rice that moved into Baodun were likely temperate species of *O. japonica*.

Other factors can create complications for farmers wishing to carry out rice agriculture, namely the large amounts of heat units required by these crops for proper growth. Compared to *O. indica* varieties of rice, *O. japonica* requires relatively high temperatures in order to achieve maturity and a long growing season (for traditional varieties) (Yoshida 1981) (see table 5.6). An analysis of growing degree days reveals that the number of growing degree days available in a region created important challenges to the movement of rice into Southwest China. Maps of growing degree days for rice were created using the methodology described in chapter 4 and by setting a 10 °C lower threshold and an upper threshold of 35 °C.

As discussed in chapter 5, there is no reason to believe that *O.indica* varieties of rice had made it to China by this point in time, although this hypothesis has not been tested yet with the help of genetic evidence. I thus decided to examine the distribution of *O. japonica*. Temperate varieties of *O. japonica* adapted to Northern China require a minimum of 2500 GDD to sustain growth. An analysis of the potential niche of these crops revealed that these varieties could grow in an area largely similar to that of *O.indica*, however, an additional area around Kunming presents difficulties for rice's growth (Figure 7.11). The analysis of growing degree days required for temperate varieties of *O.japonica* reveals that under contemporary conditions, the site of Haimenkou was outside the range of rice cultivation, as were potentially sites related to the

Jigongshan culture in northwestern Guizhou. This is not altogether unsurprising as the main crop grown around the site in the present are winter varieties of wheat (Personal observations by Richard Meadow: June 2008).

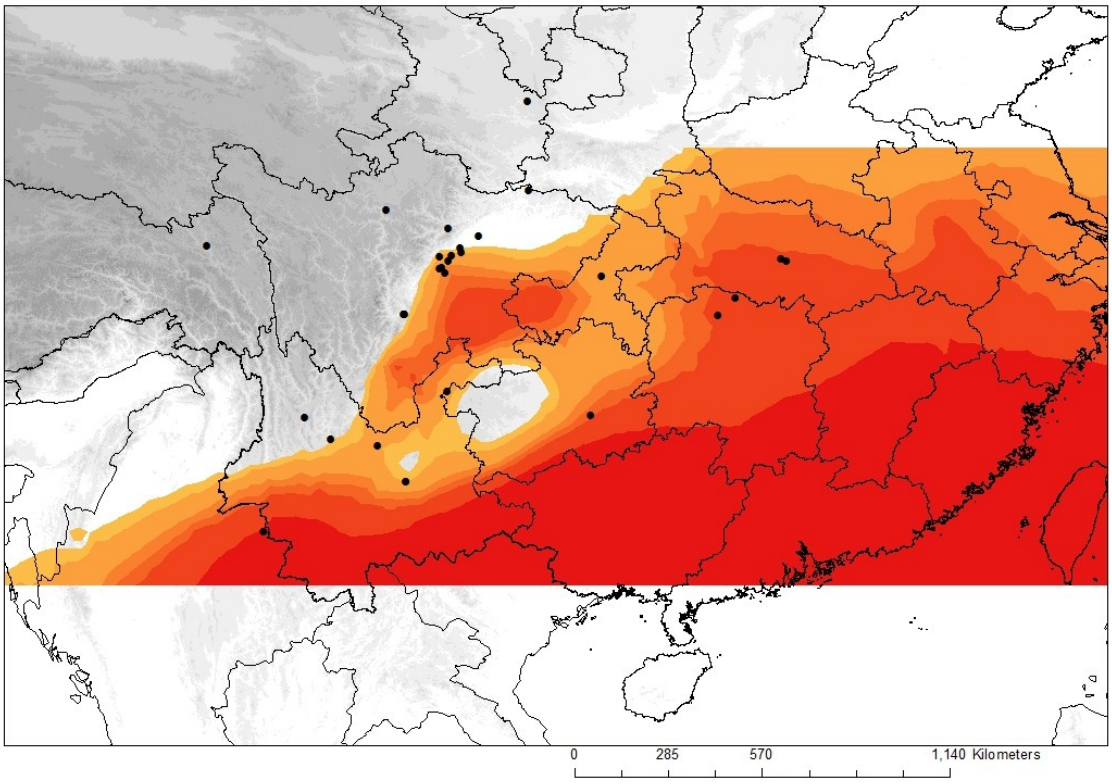

Figure 7.11 Map of growing degree days of temperate *O. japonica* adapted to Northern China (2500 GDD). Data processed using a 10°C lower threshold and a 35°C upper threshold.

While some areas presented sufficient average numbers of growing degree days for rice's growth, I also decided to examine, how frequent the risk of failure was in modern conditions. A map exploring the percentage of years a crop would fail in modern times, shows that throughout the entire Eastern portion of Southern and parts of Northern China there was little to no risk of failure in rice crops. Southwest China, reveals, however, a very different pattern. Throughout

much of southwest China, including the Sichuan Basin, Central Yunnan (through Tencheong, Kunming and Chuxiong) as well as in Bijie and Xingren counties in Guizhou, the risk of failure of varieties of *O. japonica* adapted to northern China ranged between 13-40% (Figure 7.12). At Haimenkou, the risk of failure ranged between 40-67%. In contrast, on the Chengdu plain between 7-13% risk of failure is present. In the Three Gorges, the risk also appeared to be low: under 7%, however, the lack of data points in the areas of higher altitude in this area may mean that the values for growing degree days in this region were even lower.

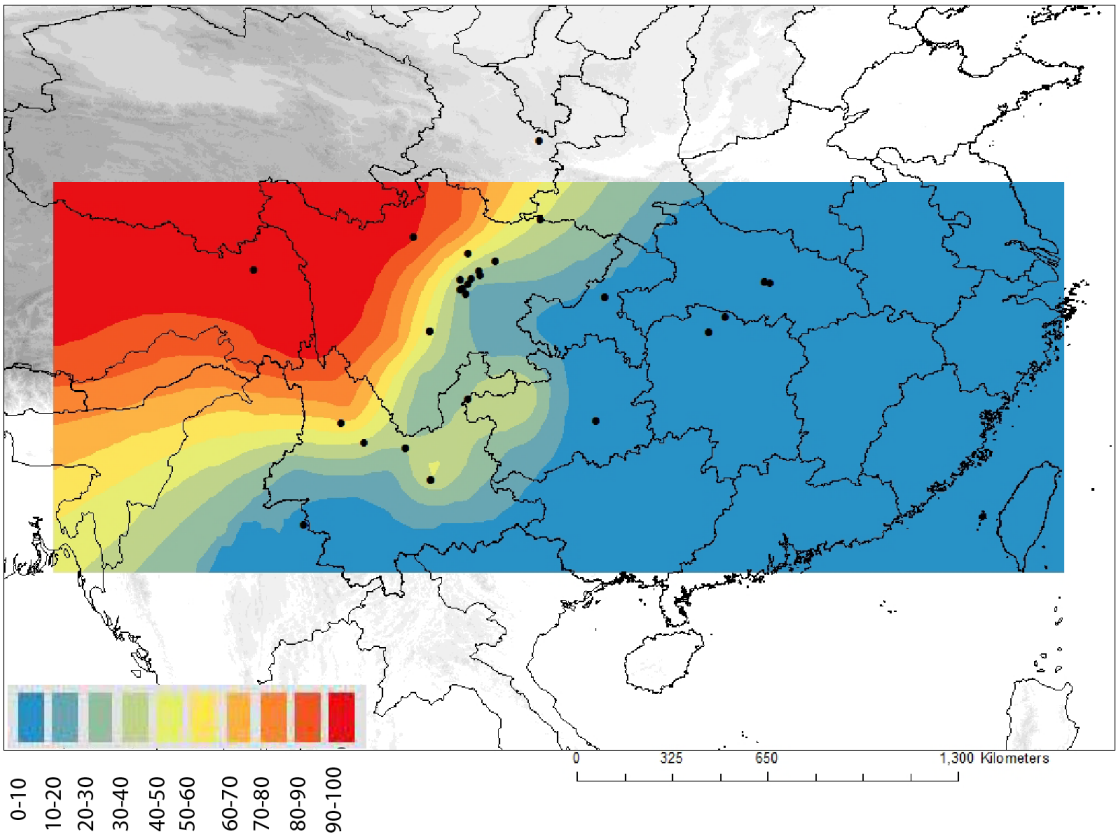

Figure 7.12. Map of risk associated with practicing temperate *O. japonica* adapted to Northern China (2500 GDD). Data processed using a 10°C lower threshold and a 35°C upper threshold. Numbers represent the total percentage of years where failure occurred.

A total of 2900 GDD are required for short season tropical *japonica* rices adapted to Southern China. As one can see in figure 7.13, large areas of the Three Gorges as well as the Yunnan-Guizhou plateau do not present sufficient numbers of growing degree days to successfully grow rice, and farmers would have experienced high chances of loss when trying to move this crop into this region. There are, however, some visible problems with this map. Although the Chengdu Plain presents sufficient amounts of growing degree days, the large numbers of points in the highlands surrounding the plain have dragged the values in the Sichuan basin down. What is clear here is that large areas of the Yunnan Guizhou plateau (including the entire western part of Guizhou and the whole of Northern Yunnan), the Three Gorges and Western Sichuan would have had great difficulty in growing these varieties of rice.

The analysis of risk also reveals that although rice could grow in parts of this area, there was an over 50% chance of failure, making tropical varieties of rice a risky endeavor for early farmers (Figure 7.14). Modern long season tropical varieties of rice adapted to Southern China requiring over 3300 growing degree days were found to be able to grow in only deep southern China. As these varieties also cannot be grown in the lower or middle Yangzi, it is highly unlikely they were involved in early agricultural practice, and thus I no longer consider them here.

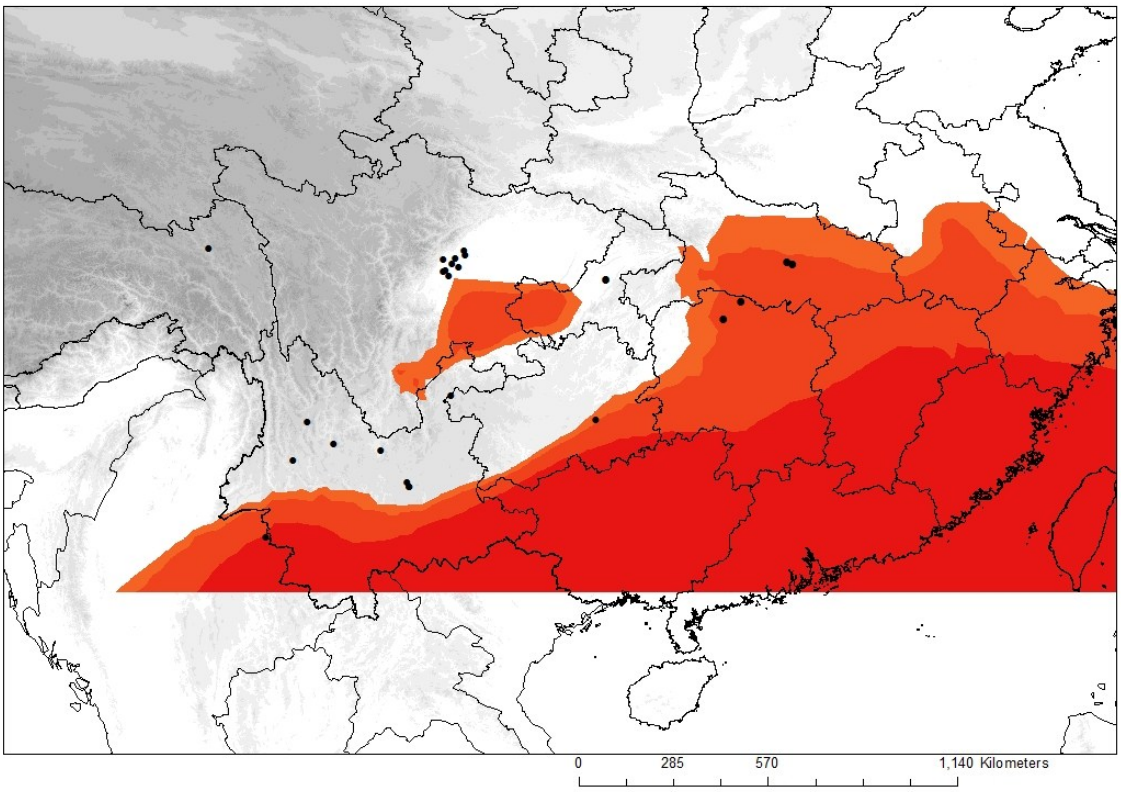

Figure 7.13. Map of accumulative growing degree days required for tropical *O.japonica* species adapted to southern China (120 day varieties): 2900 GDD

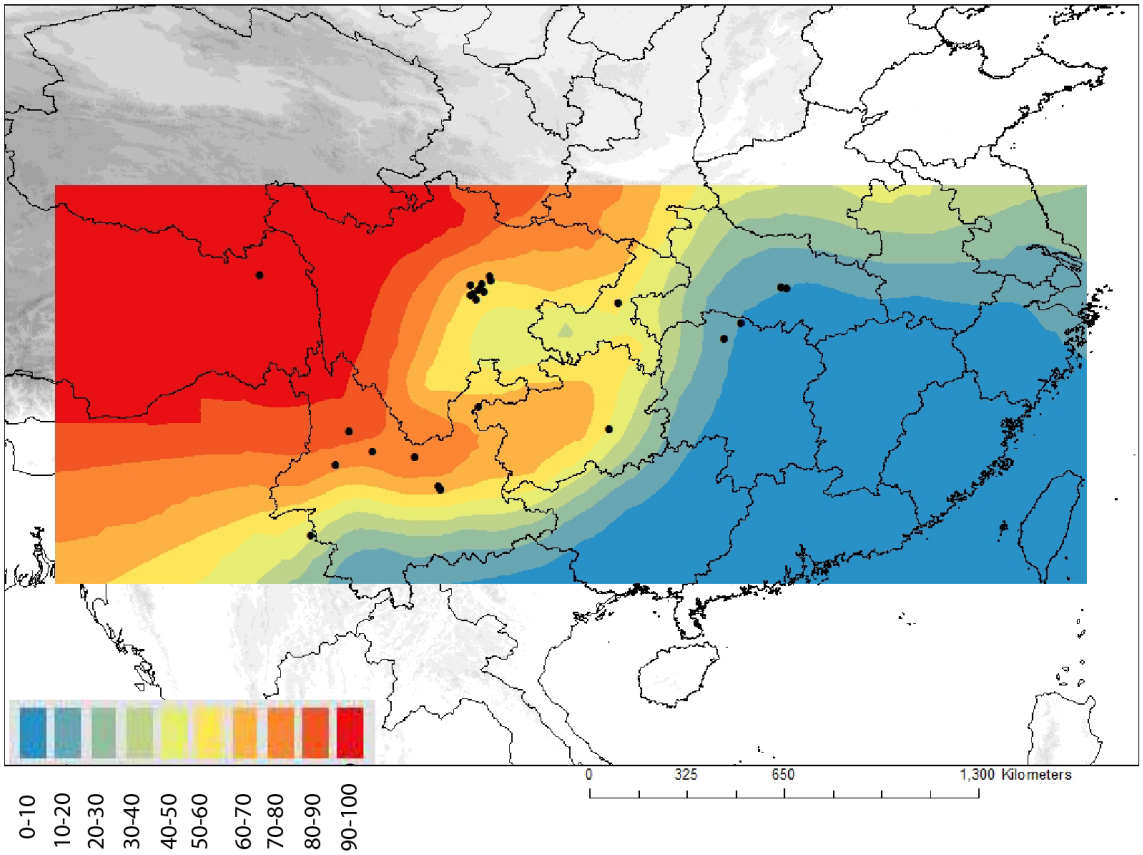

Figure 7.14 Map of risk associated with growing tropical *O. japonica* species adapted to southern China (120 day varieties): 2900 GDD.

In conclusion, an analysis of the potential niche of temperate and tropical varieties of rice, achieved by mapping the numbers of growing degree days available in different regions, reveals that it is highly likely that temperate varieties of *O. japonica* were involved in the spread of agriculture to southwest China. The smaller amounts of heat units required by these varieties meant that they were able to occupy significantly larger territories portions of the Yunnan-Guizhou Plateau and the Three Gorges. Even, though tropical varieties were able to be grown in the Sichuan Basin, the risk of failure was high (over 50%). That temperate varieties may have been involved in the spread of agriculture to this region is also supported by the morphometrics

of the rice from Baodun, which are much smaller and squatter than that known from other regions, showing similarities only to the temperate varieties from northern China.
The initial movement of rice agriculture into the Chengdu Plain appears to correspond to the warming phase hypothesized to have taken place between 3200-2500 BC, where temperatures were roughly 3°C higher than today. This warmer phase may have facilitated the initial movement of rice agriculture into this region.

Regardless of the variety of rice examined, the site of Haimenkou falls consistently into either a no grow zone or a zone of very high risk for rice, at least under present-day conditions. This is interesting, given that rice was grown during the initial phases of occupation of the site (c. 1600-1400 BC). While this period does not correspond to a climatic optimum, it falls outside the two events of lower temperature hypothesized as taking place c. 2000 BC and again at 1200 BC. Following 1400 BC, rice altogether falls out of the diet to be replaced by millets and eventually by western domesticates. This illustrates not only that the rice phenology did constrain its movement into highland Yunnan and Guizhou, but that these areas were highly susceptible to the effects of climate change. Overall, these ecological factors led to rice being a rather short lived experiment at the site of Haimenkou.

Foxtail millet, in contrast, has a shorter growing season than rice and is tolerant of both aridity and low temperatures (Cardenas 1983; Saseendran et al. 2009). It is thus well adapted to the upland and foothill environments that form a major feature of the landscape across much of Southwest China and would have provided farmers with the flexibility to expand into the drier and cooler upland territories that characterize the foothills of the Three Gorges, Yunnan and

Guizhou. Growing foxtail millet would have helped farmers who were moving into new environments maintain subsistence versatility and reduce their risk by employing a crop that could be adapted to the varying altitudes, moisture regimes, temperature and climatic conditions that characterize the landscape of the region. As Figure 7.15 shows, foxtail millet could be cultivated across the entire area of Southwest China, aside from a region of particularly high altitude around Litang, Ganzi and Songpan in western Sichuan and Deqin in Northwest Yunnan.

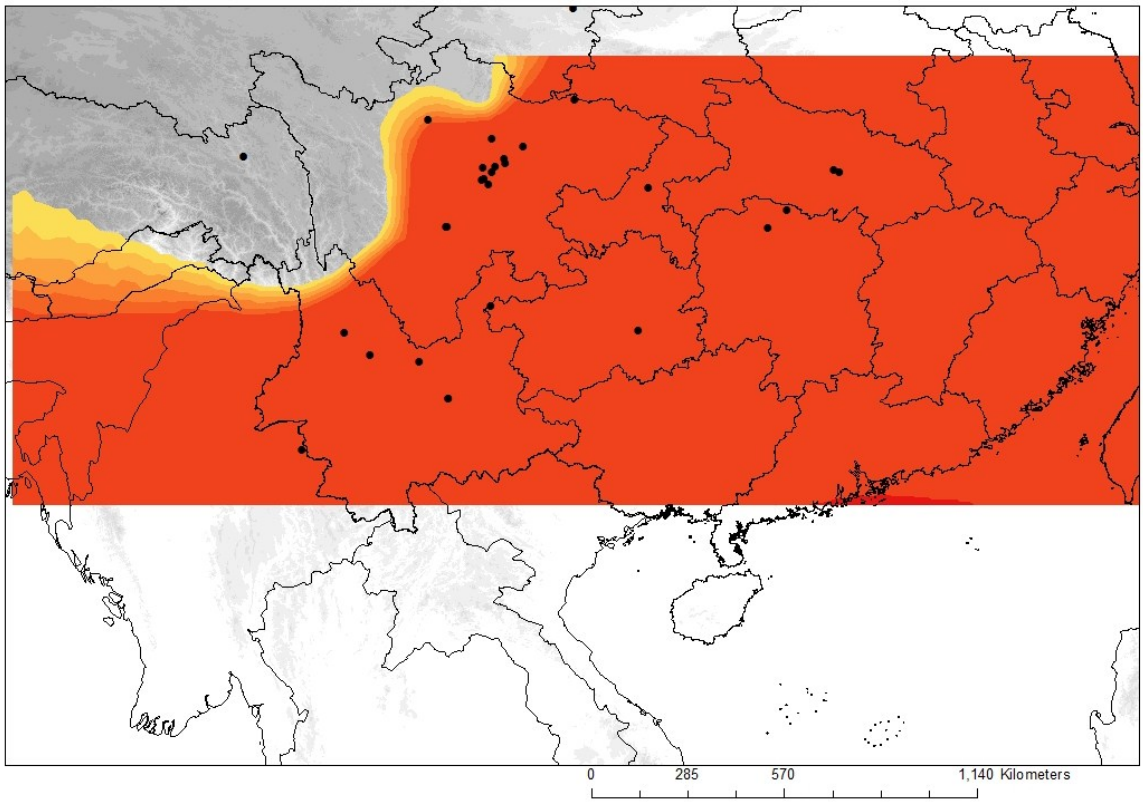

Figure 7.15 Map of the potential niche of foxtail millet in Southwest China. Map was created on a 5.5 °C base. Data processed using a 30°C upper threshold.

For foxtail millet agriculture, the risk of failure lies at 17-32 % in Northwest Yunnan and parts of the first mountain cordillera of western Sichuan (Figure 7.16). The site of Haimenkou falls just below this belt and here a risk of practicing foxtail millet was below 17%, however, it can be

assumed that given past climate changes these patterns would have been substantially different according to different phases in prehistory. These modern risk values for foxtail millet are much lower than for rice, and it is not surprising that at Haimenkou this crop appears to have been grown in at least equal proportions to rice during the phase following layer 8.

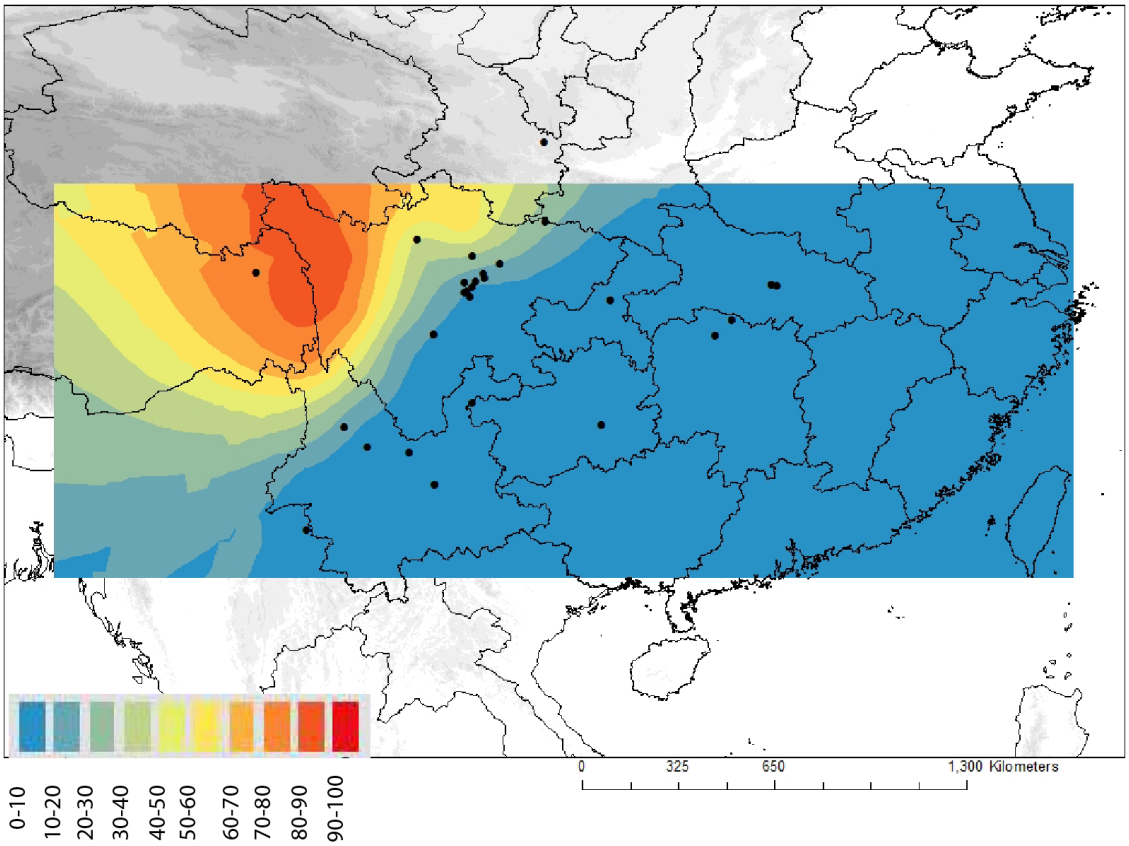

Figure 7.16 Map of risk associated with growing foxtail millet

Growing rice was a risky endeavor in the Yunnan-Guizhou plateau, the Three Gorges and the Sichuan Basin. Aside from Northwest Yunnan, farmers were able to grow temperate varieties of rice adapted to Northern China in much of this area. In addition to constraints associated with temperature, growing rice in this region presented several other important challenges. The analysis of weed flora carried out in chapter 8 and at the site of Haimenkou by Xue (2010)

suggests that the types of rice cultivated in Southwest China were grown in a paddy environment. As a result, these varieties required large expanses of flat land and ample water resources to flood them if they were to be highly productive. Creating rice paddies in the mountainous and uneven terrain of the Yunnan Guizhou plateau would have required relatively large labor investments to flatten land to create paddies and terraces and to create irrigation systems capable of bringing water from rivers and lakes to areas or higher altitude, or diverting water from mountain streams. In fact, historical sources such as the *Manshu* (Book of Southern Barbarians) suggest that the systems of terraced paddies that we associate with the landscape today do not pre-date the Tang dynasty (618-907 AD) (Bouchery 2010).

It is likely that on the Yunnan-Guizhou plateau, rice agriculture was limited in scope to selective zones, such as the flat expanses surrounding lakes like Dian or Erhai. Here the larger flat areas surrounding the lakes and the shores of the lake could have been turned into either the floating field systems, dyked poldered fields or *shatian* (sand fields) on the banks of the lake. According to Bray (1994) these fields were in use on lake Dian as late as 1990. The relatively small number of weather stations across this region meant that the analysis of growing degree days could only take into account averages over the Yunnan-Guizhou plateau, and was not able to accurately account for differences in growing degree days between a valley bottom where rice may have been cultivated and a nearby mountain peak. Although our co-kriging corrected for the effect of altitude, it was not able to provide an accurate enough map to correct for small regional differences such as these. These differences may, however, have been important in allowing for crops like rice to be grown in small quantities in northern Yunnan.

In contrast, the Sichuan Basin contains high enough measures of cumulative growing degree days to allow temperate varieties of rice to be grown. In particular, the large flat expanse of the Chengdu Plain with its ample water sources presented an ideal environment for wetland rice production, one that shared some key characteristics with the middle and lower Yangzi. Discussions with local farmers have revealed that paddy construction in the low-lying Chengdu Plain requires relatively little investment of labor (interviews carried out in December 2010). The many large rivers that crisscross the plain would also have provided a readily accessible source of water for flooding paddy fields. When farmers familiar with both millet and rice agriculture moved into this area, possibly from further downstream on the Yangzi (although a great deal of further research is need to test such hypotheses), they exploited these advantageous conditions by carrying out rice agriculture, which could easily be intensified.

By concurrently using foxtail millet, either as a fallback or as a late season crop, these farmers gained in both risk reduction and yield, spurring population growth and the development of social complexity. The walled sites of the Baodun culture show some of the earliest traces of the complexity in the Chengdu Plain that this agricultural system was able to support. Sustained by a reliable, intensifiable, and highly productive agricultural system, the Chengdu Plain later became the center of important social networks as is epitomized by the spectacular bronzes from the sites of Sanxingdui and Jinsha (see Chapter 8 for discussion). Following this period, the plain turned into an important breadbasket for Chinese states throughout the dynastic period (Sage 1992). I argue that in areas where the ecological and topographic conditions allowed for practicing rice agriculture, it was soon intensified and spurred population growth and the development of social complexity. By contrast, trajectories to social complexity in the Yunnan-Guizhou plateau

followed a different pattern, and the transition to higher population densities and social complexity appear only during the Dian period (c. 400 BC). Prior to this date, agriculture supported lower population densities, allowing farmers the flexibility to experiment with new agricultural strategies as they supported smaller populations.

In the early stages of agricultural expansion into the highland areas to the east and south of the Sichuan Basin, emphasis on foxtail millet may have facilitated movement into these more challenging vertical topographies. In areas such as the highlands of the Yunnan-Guizhou plateau, foxtail millet (and later western domesticates) provided a reliable and easy to manage alternative in an environment where the risk for failure of rice agriculture was high. Data from Haimenkou support this hypothesis. Xue's (2010) and Jin's (ND) analysis of plant remains from the site indicates that experiments with rice agriculture were short lived, lasting only 200 years between 1600-1400 cal BC, and rice was quickly replaced by foxtail millet and eventually by western domesticates like wheat. While subsistence strategies on the Chengdu Plain were characterized by a high degree of stability in agricultural patterns (see also discussion in chapter 8), in the Yunnan-Guizhou highlands, more challenging environments meant that humans were required to experiment with different solutions to meet their needs. This experimentation appears to have begun by expanding the range of foods cultivated by the inhabitants of the site to include broomcorn millet, wheat, barley and even wild foods like *Chenopodium*. This strategy of diversification is one that can be used by societies dealing with risky environments (Marston 2011). Even today, around Haimenkou, small field plots are used to plant a wide variety of crops (Richard Meadow: Personal Communication 2012), possibly to buffer against potential failure.

Foxtail millet (and later on other western domesticates such as wheat and barley), were crucial in allowing an agricultural lifestyle to move into previously uncolonized areas and facilitated expansion into new orographically defined territories such as Yunnan and ultimately into Southeast Asia. The introduction of systematic archaeobotanical analysis to Southwest China will allow us to further test these hypotheses and to understand the role that crops and their environments played in shaping human history in the region, and in turn how humans adapted their technology and agricultural systems to shape them.

In addition to ecological factors, cultural factors may also have helped determine the kinds of agriculture carried out at these sites. One could argue that sites of the Baodun culture correspond to a phenomenon of moving farmers who brought with them an already developed repertoire of crops. On the other hand, in the highlands of southwest China it is likely that populations of hunter-gatherers or low level millet agriculturalists who had a history of long distance exchange took up agriculture. One could argue that this more flexible cultural mindset allowed them to "shop at the Neolithic store"(Robb and Miracle 2007:102), taking up crops that were able to fit their needs. Regardless of the identity of the individuals involved in this spread, this analysis shows that humans occupying southwest China adapted their agricultural strategies to meet the constraints faced by difficult environments in a dynamic fashion.

7.7 Human Niche Construction and the Introduction of Champa Rice

Although much of the Yunnan-Guizhou plateau presented difficulties for growing rice in prehistory, today large areas of this plateau are transformed into terraced rice paddies and form

some of the most productive agricultural land in China. This transformation was the result of a combination of intensive human niche construction and advances in crop breeding. Following a massive defeat by Mongol armies in 1127, the Northern Song dynasty moved to southern China to establish the Southern Song, along with populations of refugees. Population had grown under the early Song and devastation of war in the North led to a huge southward push in population (Bray 1984). In the early part of the Song dynasty, a variety of early ripening rice were introduced to China from Champa in Vietnam by the emperor Zhenzong in order to alleviate a famine. The first variety of rice, which was called Champa after its region of origin, was more drought resistant and could be grown in areas where earlier varieties of rice had failed, especially on hills and areas where water production was controlled with difficulty (Simoons 1991; Zeng 1998). In addition, this rice had a short growing season (60 days). In the north this allowed rice to be grown in areas where rice productivity had been impended because of the short growing season and in the Jiangnan area it allowed farmers to grow two different crops to increase productivity.

By 1012, this variety was introduced to the lower Yangzi and Huai River valley. The introduction of this rice not only extended the cultivable zone of rice production but also increased productivity in low lying areas, which were core for the production of rice. During the Song dynasty methods of irrigation and terracing also improved dramatically opening up new zones of cultivation. In areas such as the Chengdu Plain, the low altitude, non vertical landscape and ample water supply mean that rice agriculture flourished and demographic expansion in this region is historically attested as early as the Han. On the other hand, the highlands of the Yunnan Guizhou plateau, with their highly vertical landscape, required both the introduction of new

varieties of drought resistant rice as well as extensive terracing operations to fuel any real population expansion. Population in this area did not truly grow until the 13th century, when the government began efforts to move new settlers into this area. This *tuntian* regime gave farmers seeds, draft animals and helped them clear forest on the hilltops, facilitating population expansion into this region (Lee 1982). It is largely during this period that the hilltop paddies that today characterize this region were developed.

Prior to the development of the technology of the terracing systems, it is estimated that only 6% of the total surface area of the Yunnan-Guizhou plateau was arable, and this arable land was confined to scattered valley bottoms (Lee 1982). Population expansion in early periods was thus largely confined to areas such as the Dian and Erhai lakes where crops were grown along the irrigated banks. Double cropping in this area is only possible up to altitudes of 800 meters (Bouchery 2010).

The introduction of this new variety of rice and the expansion of terracing technology was in large part responsible for the increase in population density, which occurred during the early Song. Around this time, other crops such as Sorghum were introduced to China from Africa, further expanding the range of millet cultivation in this area (Warman 2003). Thus although population pressure created important motivations to find new varieties of crops that could sustain a growing population, cultural values that dictated the importance of rice meant that the emphasis was put on finding new varieties that fit into this cultural taste rather than an emphasis on a change in crop repertoire. Thus although ecological conditions and plant phenology influenced how humans adapted their agricultural systems to southwest China, they also actively

modified and constructed the niches associated with these crops in order to ensure the continuation of foods that had important cultural meaning. When cultural values demanded it, humans not only engaged in some of the most amazing feats of niche construction by investing considerable labor into terracing systems, but they also found ways to modify the biological properties of plants themselves through breeding.

Summary

The earliest known spread of rice agriculture to southwest China appears in sites of the Baodun culture of the Chengdu Plain c. 2700 BC. Sites of this culture already contain some evidence of social complexity, hinting at moderately high population densities and cultural similarities shared with sites of the middle Yangzi. Although nearby sites in the middle Yangzi have evidence of rice agriculture almost 3000 years earlier, a long delay of time is apparent between the middle Yangzi evidence and its spread into this region. This chapter argues that the high numbers of growing degree days required by rice presented challenges to its movement into the areas surrounding the Sichuan Basin (i.e, the Three Gorges and Yunnan-Guizhou plateau). My study of rice morphometrics indicates that one of the reasons underlying this delay could be that it was necessary to wait for the development of temperate varieties of *O. japonica* in order to successfully move into this region. Following their movement into the Sichuan basin, the warm conditions and ample water resources presented by this area allowed agriculturalists to intensify rice agriculture. This had important implications for the development of social complexity in the region. Evidence from highland Yunnan shows that here, in contrast, practicing rice agriculture

was a risky endeavor and ultimately this agricultural system was abandoned in favor of a return to millet agriculture, followed by the use of western domesticates. However, in historical periods, cultural values dictating the importance of rice led to technological innovations in plant breeding and niche construction (terracing) that led this region to became an important producer of rice.

CHAPTER 8

AGRICULTURAL STRATEGIES ON THE CHENGDU PLAIN

Following the introduction of rice and foxtail millet agriculture during the Baodun period, the Chengdu Plain became an important center of social complexity. This chapter examines the kinds of agricultural strategies employed by the inhabitants of the Chengdu Plain from the Baodun until the end of the Bronze Age.

8.1 The Bronze Age of the Chengdu Plain

Following the Baodun period, four important phases of occupation are present in the Chengdu Plain. These are the Sanxingdui (ca. 1700-1150 BC), Shi'erqiao (ca. 1200-800 BC), Xinyicun (ca. 800-500 BC), and Qingyanggong Phases (ca. 500-300 BC).The site of Sanxingdui is the type site and contains important information for understanding the transition to the Bronze Age in this region. The site of Sanxingdui was discovered in 1934 when researcher D.C. Graham was brought to the site following the discovery of large jade disks (Bagley 2001; Pirazzoli-t'Serstevens 2001; Thote and Bagley 2003). Although excavations were also carried out at the site during the 1950s and 1960s, attention truly became focused on the site during the 1980s following the discovery of two large pits filled with bronzes and other precious objects (Sichuan Sheng Wenwu Guanli Xieyuanhui 1989). The pottery assemblage found at this site forms the basis for understanding the Sanxingdui period. The pottery assemblage is composed of tripod pitchers with pouched shaped feet (*he*), high stemmed bowls (*gaobing dou*), jars with a tapering profile and a small flat bottomed guan (*xiaopingdi guan*), and handles in the shape of birds with

hooked beaks (Flad and Chen 2013; Xu 2008). In the later Sanxingdui period, chalices (*gu*), *zun* shaped vessels and collared tripods are also introduced. Occupations dating to the Baodun period were found at the site (Sanxingdui I), as were two different periods of Sanxingdui occupation: the early period (Sanxingdui II), which dates from 1800-1400 BC, and the late period (Sanxingdui III), which dates from 1400-1200 BC.

Relatively little work has been done so far on the layout of the site itself, however, recently a few scholars have drawn attention to this topic (Sun 2013). Like many of the sites dating to the Baodun period, the site of Sanxingdui is surrounded by a site wall, which is larger than is common for Baodun period sites, possibly showing an increased ability to harness larger labor forces (Flad and Chen 2013). Remains of housing structures, a cemetery and large buildings were unearthed at the northwestern corner of the site (Sun 2013). The large size of one of these structures (over 50 m long) has lead some scholars to interpret it as being a palace-like building (*gongdian jianzhu*) (Sun In Press). In the remainder of the site, a number of wattle and daub houses have been discovered. While the majority of these are small, with an average of 15-30 sq. meters, some were larger, indicating potential social differentiation. Among them there is one house that was considerably large, with a surface area of over 200 square meters. Larger houses and ritual installations were concentrated in the southern part of the site, leading Sun Hua (2013) to argue that a division of space may have occurred between areas reserved for ritual, elite residences, and spaces inhabited by commoners.

Most of the discussions of the site and culture of Sanxingdui have focused on the contents of two ritual pits (Bagley 2001; Pirazzoli-t'Serstevens 2001; Thote and Bagley 2003) (K1 and K2) that

are believed to date to the final phases of the site (c. 1200 BC) (Xu 2008). A very large number of bronzes and other artifacts that were used for ritual activities were unearthed from these two pits and include a large bronze statue, anthropomorphic heads, jade disks, bronze trees, and bronze vessels. While some of these artifacts are of local manufacture, some of the objects unearthed from the pits at Sanxingdui may have been obtained through long distance trade. Falkenhausen (2003) has noted the similarity between the miniature heads and animal imagery found at Shijiahe culture sites (2500-2000 BC) and at those of the Sanxingdui site. Despite other connections with middle Yangzi sites such as the presence of walled sites, these sites are separated by over a millennia and no clear linkage can be made. Xu (2008) proposes that earlier versions of anthropomorphic statuettes could have been fashioned out of wood, hence the lack of visible continuation in the Baodun period.

The bronze artifacts at the sites also point to a wide range of connections between the inhabitants of the site and outside cultures. The method of bronze casting used in the production of the sculptures at Sanxingdui appears to be very similar to that of the Central Plains of Northern China, employing casts of clay molds to produce parts of sculptures. However, the joining techniques used in these bronzes appear to be of more local origin (Xu 2008). In addition, anthropomorphic statues are not part of the Central Plains repertoire. In addition to sculptures, ritual bronze vessels were also uncovered in these pits, which show similarities to Shang vessels from the Central Yangzi. A bronze plaque inlaid with turquoise was unearthed at Sanxingdui is similar in form and iconography to one found at the Erlitou site, hinting to cultural contact with the Central Plains region during this period.

A lead isotope study on Sanxingdui bronzes indicates that these bronzes contained HRL (High Radiogenic Lead) and the raw material for them was likely derived from Yunnan, suggesting that they may have been cast locally (Jin, et al. 1995). HRL has, however, also been found in Shang bronzes from the Central Plains, which has led Liu and Chen (2012) to suggest that Sanxingdui supplied metal to the Shang. Recent finds of bronzes in the Hanzhong basin suggest that this region may have played a role in facilitating these exchanges. Xu (2008) argues that a bronze foundry may have only been established at the site in the second phase of its occupation. As a result, he suggests that the development of the Sanxingdui culture should be understood as closely related to the Erligang expansion. Xu (2008) also argues that during the transition from Sanxingdui I to Sanxingdui II, intensive interaction took place between the cultures of the middle Yangtze and the Chengdu Plain, as reflected in the pottery repertoire, small animal figurines, and iconographic similarities in jade decoration to Changjiang jades. The Hanzhong basin may have also provided a route for the spread of these jades. Despite the extensive nature of the outside contacts, the inhabitants of the site of Sanxingdui maintained, there was never evidence for whole scale adoption of any of their neighbors' repertoires or practices. It is interesting to consider the effect that regional exchange could have had on traditions of food practice and on agricultural strategies.

Other known sites relating to the Sanxingdui period include: Yanduizi, Guilinxiang, Qingjiangcun, Hetaocun, Songjiaheba, Shaxi, Shuiguanyin, Zhonghai and Sanxingcun, however, none of these are surrounded by the large walls known from Sanxingdui itself (Flad and Chen 2013; Sun 2013). In addition to the nature of finds at Sanxingdui, this suggests that this site may have served an important function as a central place. The overall lower number of sites

associated with this period and the concentration of a large number of ritual paraphernalia at a single site suggests that some restructuring of social order did occur during this period, however, the nature of this restructure remains unclear.

The emergence of social inequality has become an increasingly important research theme around China. The large scale of the settlements present on the plain during the Baodun and the Sanxingdui period hint at a high degree of social complexity in this region, however little work has been carried out on how these societies were structured. Given the apparent lack of hierarchy in burial ritual during this period of time, it is difficult to approach this question. Sun Hua (2013) has argued that the variety of different hairstyles on the anthropomorphic heads unearthed in the pits at the ritual center at Sanxingdui can shed some light on ancient social structure in this region. He argues that individuals with braided hair represented the inhabitants of the Sanxingdui site, whom he further divides into a ruling class and the ruled. In contrast, individuals with hair tied in buns are interpreted as representing individuals from hostile states or communities. Within the ruling class, Sun differentiates between two different kinds of elites: ritual specialists and those who held political power. The degree to which power at Sanxingdui was divided between political (secular) and religious specialists are unclear.

It is, however, clear from these pits that a great deal of effort and time was spent on ritual structure, indicating the presence of some kind of class of ritual specialists. What is not clear is whether or not these ritual structures articulate with a clearly formed social hierarchy. If the graves at the site of Sanxingdui are any indicator, the site appears to have been marked by very little social stratification. Flad and Chen (2013), suggest that the numbers of bronze statues at

Sanxingdui suggest that a relative shift in the importance of individuals occurred during the transition from the Baodun to the Sanxingdui period. They argue that individuals engaged in political action sought to solidify networks with outside areas, rather than in corporate or group oriented strategies.

It is, however, unclear if this is truly the case: As Flad and Chen (2013) point out, many of these bronze sculptures were placed on wooden sculptures and it is possible that wooden representations may have been used in earlier periods. In addition, whatever prestige or privileges these individuals gained in life, it does not appear to have extended to in the grave as no marked hierarchy exists in the few known burials from this period. In comparison to sites in northern China at the same period, sites on the Chengdu plain differ in one other important regard: They lack any evidence of human sacrifice. Whatever power the ritual specialists at Sanxingdui acquired, it does not appear that their power extended over that of life and death of other individuals.

8.1.1 Archaeobotanical Samples from Sanxingdui period sites:

I was able to obtain samples related to the Sanxingdui period from three sites.

a.) Zhonghai

Excavations carried out at locale 2 of the site of Zhonghai in 2004, only yielded remains dating to the Bronze Age. A very large sample was collected from an ashpit dating to the Sanxingdui period at this site (H26), which was directly dated to the early Sanxingdui period (1520-1425 BC)

using direct AMS dating of seeds (Chengdu Shi Wenwu Kaogu Yanjiusuo 2013). Remains relating to the early Sanxingdui period were represented by one other ashpits (H25). Both H25 and H26 were exceptionally large, and contained large numbers of intact items of pottery, suggesting an unusual pattern of discard. The excavators of the site interpret these pits as possibly being related to ritual practices. The pottery in these ashpits show clear affiliations with those unearthed at the Sanxingdui type site, including the *xiao pingdiguan*, handles in the shape of bird heads, as well as footed *pan* vessels.

Ashpit H26 (the ashpit from which an archaeobotanical sample was taken and AMS dates were carried out) was exceptionally large, having a diameter of over 2.9m and reaching over half a meter in depth. Large quantities of ash associated with fragmented animal bones were found in the pit. Four levels of stratigraphy were visible in this pit. In 2004, however, no professional archaeobotanist was on site to sample, and samples for archaeobotanical analysis were not collected according to stratigraphic layers. Some differences in the phases to which pottery belonged were visibile between the different layers of this pit, indicating that it may have been used over a long period of time (Chengdu Shi Wenwu Kaogu Yanjiusuo 2013). This makes it unlikely that this pit served as a ritual deposit and the archaeobotanical remains derived from it appear to reflect routine waste more than a singular deposit.

b.) Sanxingcun

In addition to the single sample from Zhonghai, 14 samples related to the Sanxingdui period have been retrieved from the site of Sanxingcun in Qingbaijiang in 2009. These were analyzed by Shi Tao at Peking University (Shi 2012). This site covered over 38,0000 m^2 and a large number of house features, ashpits as well as 35 tombs of which over half of these belonged to

infants. The joint burial of a male and female skeleton holding hands was also unearthed at the site. While the contemporaneous nature of these burials needs to be confirmed this may suggest that an event such as disease or famine could have resulted in the death of large numbers of infants and a few adults (Xu 2010). Futher research is needed to confirm this hypothesis.

c.) Guiyuanqiao

Only a few remains relating to the Sanxingdui period have been unearthed at the site of Guiyuanqiao. These were distributed in an uneven fashion across the southern end of the site and only one kiln and two ashpits were uncovered. Only one sample for flotation was taken from this period. A single sample relating to this period was unearthed from ashpit 31 feature at this site and yielded a very low density of seeds. The overall sparse nature of Sanxingdui period material at this site suggests that it was either only ephemerally occupied during this period of this or was a very small settlement.

Table 8.1 Description of samples from sites relating to the Sanxingdui period

Site	**Phase**	**Number of samples**	**Analyzed by**
Zhonghai	Sanxingdui	1	Jade d'alpoim Guedes
Sanxingcun	Sanxingdui	14	Shi Tao
Guiyuanqiao	Shang	1	Jade d'Alpoim Guedes
Songjiaheba	Sanxingdui (Late)	4	Jade d'Alpoim Guedes
TOTAL		20	

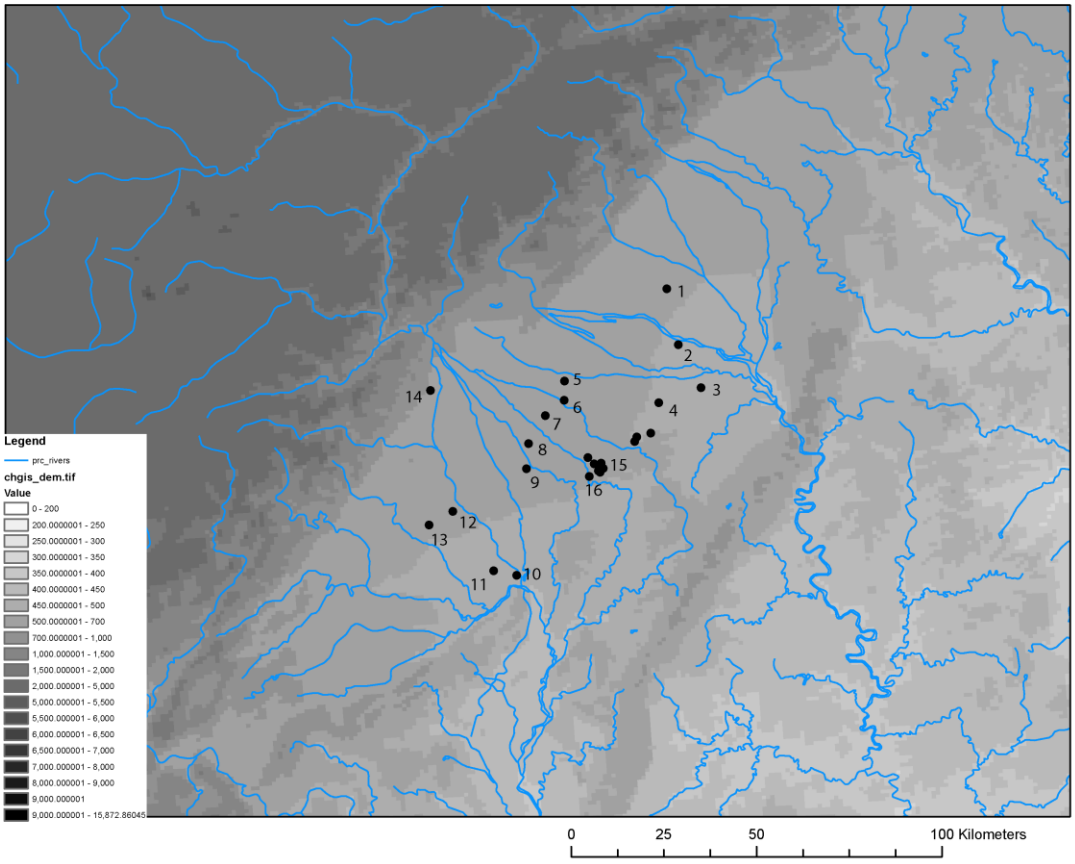

Figure 8.1 Sites on the Chengdu Plain discussed in the text 1)Guiyuanqiao; 2)Sanxingdui; 3)Sanxingcun; 4)Yangtangcun; 5)Pixian Gucheng; 6)Songjiaheba; 7)Bolocun; 8)Yufucun; 9)Yongfucun; 10)Huayuan; 11)Baodun; 12)Shuanghecun; 13)Zizhucun; 14)Mangcheng; 15)Jinsha sites; 16) Qingyang Xingchengjian

8.2 The Shi'erqiao Phase

The decline of the site of Sanxingdui is followed by the Shi'eriqiao phase, which is typically dated to 1200-800 BC. The Shi'erqiao culture type site was discovered in Chengdu City, and a large number of sites belonging to this culture have continued to be excavated by the Chengdu City Institute of Archaeology. Whether many of these localities formed separate entities or one continuous interconnected urban sprawl is unknown and is difficult to ascertain as their location

underneath the modern city of Chengdu. The Shi'erqiao locus itself contains occupations that range from the late Sanxingdui period to the Shi'erqiao phase. In fact, many of the most important features at Shi'erqiao may date to this earlier period. The appearance of pointed bottom *jiandizhan*, *jiandibei* (cups) and *jiandiguan* (jars) in levels 11-9 of the site mark the appearance of the Shi'erqiao culture. The Shi'erqiao site itself is most famous for the discovery of several large wood pile buildings in 1985 (Chengdu Shi Wenwu Kaogu Yanjiusuo and Sichuan Sheng Wenwu Kaogu Yanjiuyuan 2009). Two different buildings were unearthed and while one of these was small, the larger one has sometimes been interpreted as being a palatial structure because of its large surface area: 560 m2. However Flad and Chen (2013) have argued that there were no material finds that pointed to this building being used for occupation by elites. They argue that it may, instead have served as a kind of communal meeting hall.

The series of excavation localities that collectively form the site of Jinsha is much better known. Jinsha is composed of a series of different locales that have been the object of excavations since 1995 carried out in the Northwest part of Chengdu when this area was transformed from farmland to apartment buildings. Excavations carried out at Sanhehuayuan and Jindu Huayuan in Huangzhong Xiaoqu, uncovered the remains of tombs, a large building, kilns, and ashpits (Chengdu Shi Wenwu Kaogu Yanjiusuo 2003, 2004a, b, c, d, 2005b). However, public attention only became focused on the site in 2001, following the accidental discovery of a large numbers of precious objects and elephant tusks during the construction of a pipeline. Since 2001, the Chengdu City Institute of Archaeology has excavated over 20 locales belonging to the larger site of Jinsha including: Lanyuan, Jinshayuan, Yansha Tingyuan, Jiang Wangfudi, Furongyuan, Boyating etc, covering a total of over 100,000 square meters (Chengdu Shi Wenwu Kaogu

Yanjiusuo 2003, 2004a, b, c, d, 2005b). It is believed that the site covers over 5 square kilometers primarily distributed over the locales of Jinshacun, Longzuicun, and the Hongsecun complex in the Jinniuarea that includes Hongsecun, Langjia etc (Figure 8.2) (Jiang Zhanghua: Personal Communication).

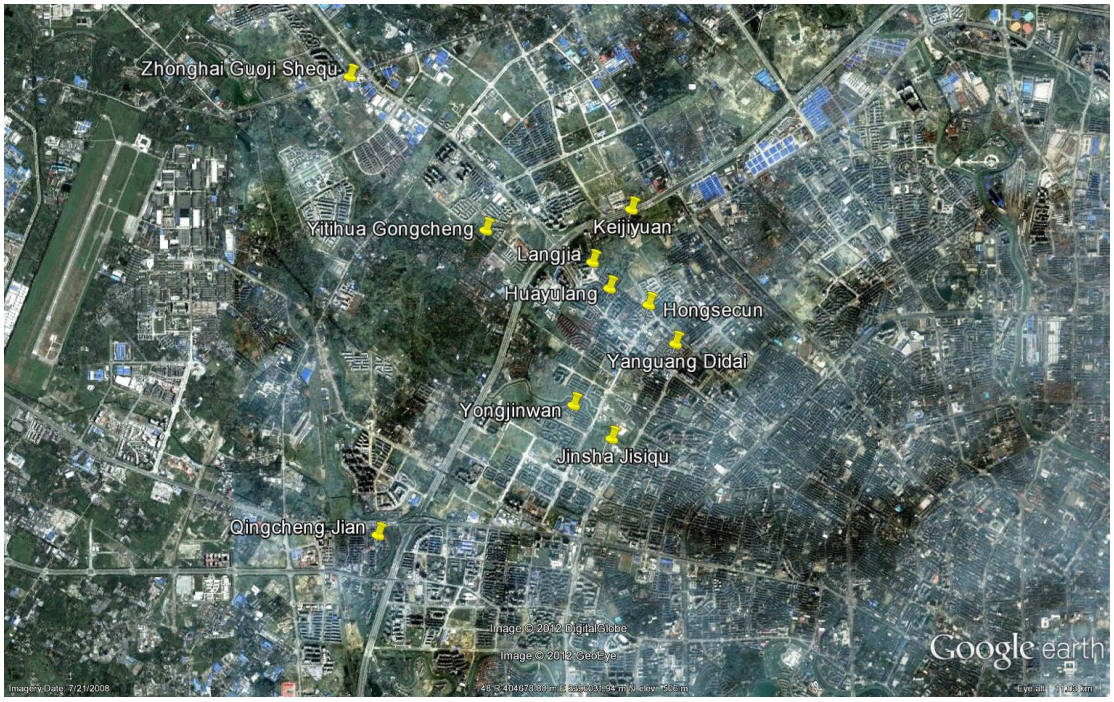

Figure 8.2 Sites within the city of Chengdu (Jinsha complex sites)

The northern part of the Jinsha site appears to been residential. The foundations of five large buildings covering over 430 m2 were discovered at the Sanhehuayuan locus in Huangzhong Xiaoqu. The remains of much smaller buildings covering only 20 m2 located nearby hint at some kind of stratification of building function. It has therefore been argued that the large building complex may have been either an administrative building or an elite residence (Zhang, et al. 2002). There is evidence that the inhabitants from this locale carried out some degree of water management, as can be inferred from a series of man made ditches reinforced with cobblestones

have been found in the northwestern portion of the site. Some (Sun 2013) hypothesize that their function was to deliver clean water to the residents. Large numbers of storage pits, disposal pits and kilns were also found in the residential portion of the site. A number of other loci containing similar remains include: A line road project, B line road project at Huangzhongcun, Taiji Huayulang, Xicheng Tianxia, Wanbo, Chunyu Huajian loac, Furongyuan and Lanyuan locus (Chengdu Shi Wenwu Kaogu Yanjiusuo 2003, 2004a, b, c, d, 2005b; Zhang, et al. 2002).

According to Sun Hua (2013), the Jinsha area can be divided into two main phases of occupation. The first phase corresponds to the transitional phase between Sanxingdui and Shi'erqiao and ranges from 1200-1000 BC. The remains from this phase are scattered, however no large buildings or ritual installations are associated with this phase. The second phase of occupation corresponds to the middle to late Shi'erqiao period (1000-800 BC) and it is during this period that the district appears to have undergone a transformation to become an important urban center. Following this the site appears to have undergone a decline and becomes transformed primarily into a cemetery between 800-500 BC).

During the Shi'erqiao period, the ritual center of the site appears to be have been centered in the southern part of the Jinsha, with a particularly high concentration of ritual activities at the Meiyuan locus (Chengdu Shi Wenwu Kaogu Yanjiusuo 2003, 2004a, b, c, d, 2005b; Zhang, et al. 2002). Sun Hua (2013) has argued that the structure here parallels that of the Sanxingdui site, with a residential center in the northern area, and a ritual zone in the south bank. The discovery of this ritual locus was accidental and large numbers of elephant tusks, gold, and jade were found by pipeline construction workers, who reported the find to the local archaeology institute. Today,

this portion of the site is housed under the "Jinsha Archaeological Park" and it will be systematically excavated in the future, although some small scale excavation of offering pits continues on a yearly basis. At the ritual *Jisiqu* or "sacrificial center", a large number of offering caches have been unearthed. These contain a wide variety of contents including jades, elephant tusks, pig tusks, deer horns, bronzes, jewelry, jades and gold masks. The few images of masks and human figurines indicate that human imagery contained to play an important role in the ideological systems of the Bronze Age inhabitants of the Chengdu Plain. Other important ritual paraphernalia have been unearthed at the site such as turtle plastrons used for plastromancy. However, compared to finds from other regions of China, these exhibit limited systematic preparation, suggesting that although they were produced in order to imitate the practices of the Central Plains as traditions tied to religious authority and power, they were not central to political authority (Flad 2008).

Several motifs that were popular during the Sanxingdui period, persist during the Jinsha phase, demonstrating a continuity in religious symbols between the two sites. These include birds with arrows, human imagery, and a preoccupation with other symbols of nature such as cicadas and a four leafed motif. The quality of bronze and numbers of bronze items dating to this period of time differ considerably from those at Sanxingdui and overall the same levels of investment in the production of ritual pieces do not appear to be shared in the Jinsha assemblages. This suggests a restructuring of ritual practice.

Other important changes appear to occur with regards to the frequency and nature of ritual deposits between the Sanxingdui and Jinsha sites (Flad and Chen 2013). Unlike at Sanxingdui, where the deposition of ritual material appears to have been concentrated in two major pits, at

Jinsha, a large number of pits containing ritual offerings have been found. Each of these is possibly related to a separate dedicatory event. Relative to the the pits at Sanxingdui, the offering pits at the Jinsha site are smaller and appear to have been created on a more regular basis. The content of these pits is also quite heterogeneous; each of them contains a unique array of cultural material. Some held only elephant tusks, others have a preponderance of personal adornments, and others again contain objects such as gold masks. While the end of the site's occupation at Sanxingdui seems to have been marked by one large dedicatory event, Jinsha appears to have been the center of a continual and sustained effort at offerings. It is possible that there was a difference in the kinds of individuals who were able make ritual offerings during this period of time. This could represent a shift from only religious specialists being able to make offerings to commoners or a larger sphere of individuals being able to participate in religious activity. Their large numbers also suggest that these offerings could have been created competitively.

Sun Hua (2013) has argued that massive social change took place between the Sanxingdui and Shi'erqiao periods. Based on differences in hairstyles on human statuary, he suggests that during the Sanxingdui period, the societal elite was divided into a secular and a religious group. He argues that changes in the hairstyles of the human statuary represented at Jinsha, show that individuals responsible for secular power now also exercised religious power, hinting at a social reorganization. Flad and Chen (2013) argue the increased presence of weapons in assemblages dating to the Shi'erqiao period signal that intercommunity violence became more common place. In addition, several stone figurines wearing loin cloths with their arms tied behind their back have been unearthed at the ritual center at Jinsha as well as at the site of Fangchijie and at Sanxingdui. Shi (2010) has argued that these sculptures are not representative of inter-personal

violence but rather of self sacrificing ritual specialists based on their association with ritual paraphernalia such as jade *zhang* and stone tigers. Flad and Chen (2013) argue, on the other hand, that these sculptures suggest that interpersonal violence may have been a focus of ritual activity. However, no human remains have been found that could support these claims, and unlike Northern China, human and animal sacrifice does not appear to have been a feature of Shi'erqiao period ritual activity in the Chengdu Plain.

A large number of graves have been unearthed relating to this period of time. Despite the fact that these have not been systematically analyzed, a cursory review of the reports containing these graves show that, unlike in previous periods of occupation on the plain, some kind of social stratification is apparent. Over half of the burials known contained no objects, and those that did mainly contained only simple pottery pieces, while a few graves were richly furnished with pottery, bronze, and jade artifacts.

Between 800-500 BC, the site appears to have undergone a massive decline, and areas previously reserved for habitation are now occupied by later Eastern Zhou period graves. In the ritual center of the site, some activity continued, and a number of offering caches date to this period.

In terms of settlement patterns, the number of sites dating to this period is significantly larger than the number of Sanxingdui period sites. This suggests that during the Shi'erqiao period an increase in population density took place across the plain as a whole. In addition, the spatial extent of sites that show close affiliations to the Shi'erqiao culture reaches beyond the Chengdu plain itself, and occupations relating to this culture have been found in the southwestern part of

the Sichuan Basin (the Shaxi site in Ya'an), and also in the eastern part of the Chongqing region (Qingyuan in Youyang county).

Zooarchaeological analysis at Shi'erqiao suggests that subsistence was heavily reliant on four domestic taxa including pig, dog, cattle and horse, which form almost 70% of the assemblage (He 2012). Hunted cervids form approximately 29 % of the assemblage (He 2012). Among domesticates, pig contributes between 57.6-63% of the available meat. This differs considerably from what is known about animal usage patterns at Shi'erqiao culture sites in the Three Gorges and here subsistence appears to have been more reliant on wild fauna, where domesticates made up only 25% of the assemblage, a number of which were likely wild boar (He 2012). Here cervids formed a much more important part of the assemblage reaching up to 58% and wild animals as a whole formed over 74%. As was noted in chapter 7, ecological differences between the Sichuan Basin and Three Gorges could have prompted these differences in subsistence practice. Additionally, other factors could also have to do with cultural uptake.

8.2.1 Archaeobotanical samples

Archaeobotanical data were derived from a number of sites relating to the Shi'erqiao period, the majority coming from the sites that collectively form part of the Jinsha complex. They come from complexes containing remains from contexts dating to the transitional period from the end of Sanxingdui, through the Shi'eriqiao period, and until the end of the Western Zhou. A number of sites also contain remains from later periods of time ranging from the Han dynasty to the Song

Dynasty. A brief description of each of the sites from which samples were derived is described below (Figure 8.1 and 8.2).

a) Yitihua Gongcheng Jiniuqu number 5 locale C 一体化工程金牛区 5 号 C 地点 (Jiang, et al. 2011)

The 5C site is located in the central portion of the Jinsha site complex and is 100 meters south of the Sanhehuayuan locus and 400 meters north of the ritual center at the Meiyuan locus. Excavations were carried out at the site between 2007 and 2008 during the course of a collaboration between Sichuan University and the Chengdu City Institute of Archaeology. A large number of features were unearthed, including the remains of houses, kilns, ashpits and tombs. The site is highly stratified and contains remains relating to a number of different periods. Samples were collected and analyzed by Jiang Ming from remains that dated to 1.) The late Shang and early Western Zhou, 2.) The Early Western Zhou 3.) The Late to Middle Western Zhou. A total of 15 samples of roughly 18 L were collected from ashpits. Samples were analyzed by Jiang Ming and Zhao Zhijun at the Academy of Social Sciences in Beijing (Jiang, et al. 2011). Samples from this site were only analyzed down to the 1mm fraction, meaning that weed seeds and rice spikelets were not systematically counted.

Samples from the following sites were all analyzed by myself down to the 0.5mm fraction. Approximately 25% of the 0.25 mm fraction was observed to remove rice spikelets. These samples reflect deposits from residential areas of the site.

A number of other samples were derived from residential loci at the Jinsha complex.

b) The Huayulang site at Jinsha Yizhi Taiji 金沙遗址泰基•花语廊工地: in the northern portion of the Jinsha site complex and contained largely residential features. Three samples were unearthed at the site in 2006 from ashpits.

c) Zhuxin Kejiyuan in Jinnuicun 铸信科技园，金牛村 5-6 组: is also located in the residential area of the Jinsha site complex and two samples were derived from ashpits during excavations that took place between the winter and summer of 2006.

d) The Hongsecun Site in the Jinniu District 金牛区红色村: A further two samples were unearthed from a nearby locale also in the residential area of the site.

e) The Languang Yongjinwan locale at Jinsha 金沙遗址蓝光雍锦: A further five samples were taken from ashpits in another residential locus

f) The Langjia relocation area in Jinnui District 金牛区国土局郎家七、八组拆迁房: An additional two samples were taken from ashpits in residential complexes in the Northwest of the Jinsha complex.

g) The Yangguang Didai locale at Jinsha 金沙阳光地带: Also located within the residential portion of the site a single sample was taken from an ashpit.

In addition to samples from the Jinsha complex itself, samples were also recovered from a number of sites in different locales on the Chengdu Plain.

h) Qingyang Xingcheng Jian Gongdi 青羊兴城建工地: is located within the modern boundaries of Chengdu City. Qingyang was excavated in 2008, located near the bank of the Jinjiang river in Central western Chengdu, close the Sichuan Provincial Museum and hence outside the Jinsha site complex. This site was dated to the Shi'erqiao period on the basis of pottery association. 10 flotation samples were taken from stratigraphic layers, kilns and ashpits.

A number of samples from sites dating to the Shi'erqiao period were also unearthed from locales outside the City of Chengdu. These include:

i) The Bolocun site in Pixian County 郫县波罗村遗址:

Bolocun was recognized during the 2009 season of the CPAS survey and excavations were subsequently carried out at the site. The site was subsequently identified as an important locus for excavation by the Chengdu City Institute of Archeology and a number of excavation units were carried out at the site. We visited the site during the winter of 2009 and extracted samples from 14 different contexts including ashpits and stratigraphic layers.

j) The Sanhehuayuan site in Xindu 新都三河花园九组:

Additional samples were taken from excavations at the Sanhehuayuan locus in the district of Xindu to the Northeast of Chengdu City. This site was excavated by the Chengdu City Institute of Archaeology during the winter of 2010. Although Baodun period activity was present at the

site, samples were only taken from 7 units (ashpits and stratigraphic layers) dating to the Shi'erqiao period.

k) The Guiyuanqiao site 桂圆桥: A number of remains dated to the Western Zhou (1046-771 BC) corresponding roughly to the Shi'erqiao phase (ca. 1200-800 BC) were also uncovered at the site of Guiyuanqiao. One tomb and a total of 20 ashpits have been unearthed. Ashpits relating to this phase were both round and square. In a number of the round pits it was clear that the walls of the pit had been previously fired. Lots of stones were placed in these pits along with pottery. 8 samples were recovered from ashpits dating to this period.

Unfortunately no radiocarbon dating has been carried out on the sites listed above and we were thus only able to attribute their contents to the Shi'erqiao period in general. More systematic analysis of the content of these sites and radiocarbon dating will help resolve their precise chronology.

A series of samples from sites dating to the early Shi'erqiao period (1200-1000) have been analyzed by Shi Tao at Peking University.

These include the sites of Yongfucun, Yantangcun, Huayuan, Taipingcun and Zhujiacun.

l) Yongfucun: The site of Yongfucun is located in Wenjiang county in Western Chengdu in the Yongning township. Excavations were carried out in 2010 and layers dating to both the Baodun

and Shi'erqiao periods were unearthed. A total of 6 samples dating to the Shi'erqiao period were examined.

m)Yantangcun 燕塘村: this site is located in Xindu distrinct to the northeast of Chengdu. Excavations were carried out at this locale in 2010, and a large number of ashpits dating to the early Shi'erqiao period were unearthed. In total, 10 samples were extracted.

n) Huayuan 花园: In addition to the Baodun samples unearthed at Huayuan in Xinjin county, 1 sample dating to the Shi'erqiao period was recovered from layer 5 of this site.

o) Taipingcun 太平村: The Taipingcun site is also located in Xindu district and was excavated in 2010. Only early Shi'erqiao period components were unearthed, and two samples were extracted from ashpits and floated.

p) Zhujiacun: 新都镇褚家村三组: The Zhujiacun site is also located in Xinjin. Initial excavations took place in 2008 (Chengdu Shi Kaogu Yanjiusuo and Xinduqu Wenwu Guanlisuo 2010), and remains relating to Baodun phases 3 and 4 and to the early Shi'erqiao period were unearthed. In 2011, additional excavations were carried out at the site and an extra 35 ashpits, four graves and one ditch were unearthed that dated to the early Shi'erqiao period. A total of 16 samples dated to this period were unearthed from layers 7 and 8.

Table 8.2 Summary of Shi'erqiao period samples examined for this dissertation

Site	Phase	Number of samples	Analyzed by
Yitihua Gongcheng 5C	Late Shang to Middle Western Zhou	15	Jiang Ming
Jinsha Huayulang	Shi'erqiao	3	Jade d'Alpoim Guedes
Jinniuqu Zhuxin Kejiyuan	Shi'erqiao	2	Jade d'Alpoim Guedes
Jinniuqu Hongsecun	Shi'erqiao	2	Jade d'Alpoim Guedes
Jinsha Languang Yongjinwan	Shi'erqiao	5	Jade d'Alpoim Guedes
Jinsha Yangguangdidai	Shi'erqiao	1	Jade d'Alpoim Guedes
Jinnui Langjia	Shi'erqiao	2	Jade d'Alpoim Guedes
Qingyang Xingchengjian	Shi'erqiao	10	Jade d'Alpoim Guedes
Bolocun	Shi'erqiao	14	Jade d'Alpoim Guedes
Xindu Sanhehuayuan	Shi'erqiao	7	Jade d'Alpoim Guedes
Guiyuanqiao	Western Zhou	8	Jade d'Alpoim Guedes
Wenjiang Yongfucun	Shi'erqiao	6	Shi Tao
Xindu Yantangcun	Shi'erqiao	10	Shi Tao
Xinjin Huayuan	Shi'erqiao	1	Shi Tao
Xindu Taipingcun	Shi'erqiao	2	Shi Tao
Xinjin Zhujiacun	Shi'erqiao	16	Shi Tao

8.3 Changes in Crop Composition on the Chengdu Plain

8.3.1 Cereal crops

In order to examine changes in the composition of crops on the Chengdu Plain throughout time, an analysis of ubiquity was carried out, and samples that contained fewer than 6 identifiable seeds were eliminated. A total of 31 samples were eliminated from the Baodun period, 6 from the Sanxingdui period and 15 samples were eliminated from the Shi'erqiao period. Unfortunately, only a small number of samples from Sanxingdui period sites have been examined, meaning that the analysis of ubiquity for this period is likely a less powerful indicator of the true patterns of crop usage. The ubiquity of rice, foxtail millet and vetch was calculated on the basis of presence of caryopsis or cotyledon. Plant parts such as spikelet bases that are recoverable for rice but not

for millets and therefore not directly comparable were excluded from determination of ubiquity. Ubiquity for Job's tears was calculated from fragmented utricles as well as from caryopsis presence, as experiments show that it is unlikely that the latter will preserve in the archaeological record.

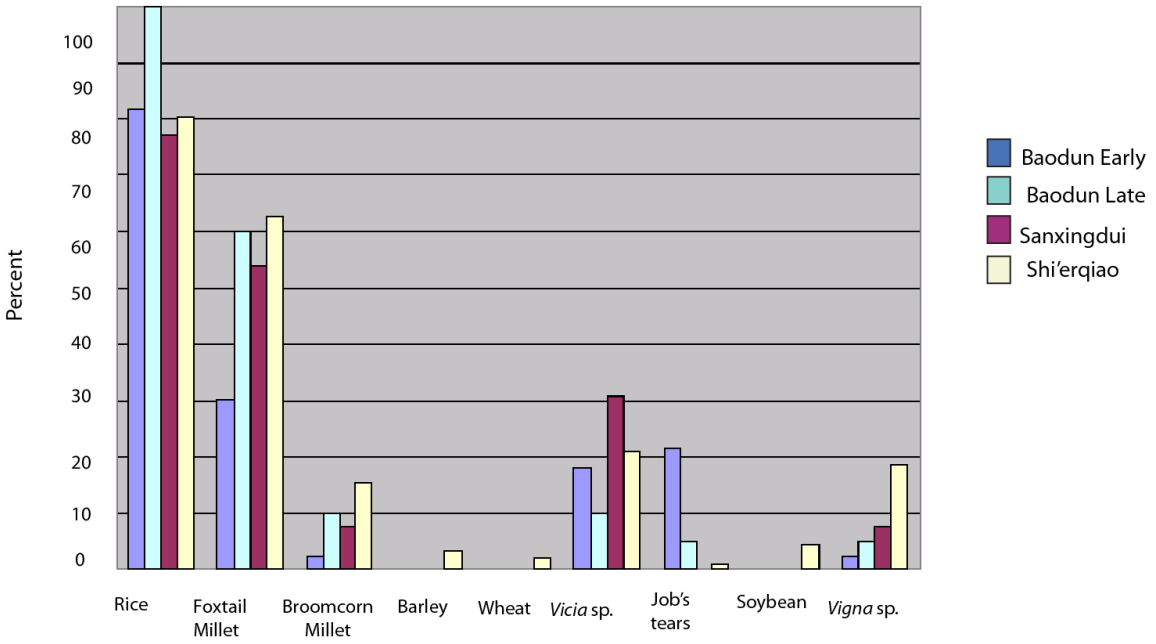

Figure 8.3. Ubiquity of main economic plants for sites on the Chengdu Plain from the Baodun to the Shi'eriqiao phase

Throughout the 2000 years documented in this study, rice consistently appears to have been the most widely consumed cereal crop of the inhabitants of the plain. The ubiquity of rice shows that it is by far the most important crop on the Chengdu Plain. Rice has an ubiquity of roughly 80% during the early Baodun, the Sanxingdui and Shi'erqiao periods and its ubiquity rises to 100% during the late Baodun phase. Following rice, the second most ubiquitous crop is foxtail millet. The ubiquity of foxtail millet increases abruptly from the early to late Baodun, rising from being

present in 30 to 60% of samples. Although there is a slight decline during the Sanxingdui period, the ubiquity of foxtail millet continues to rise during the Shi'eriqiao period. Broomcorn millet shows a steady increase in numbers between the Early Baodun and the Shi'erqiao period, where it rises from being present in 2% of samples, to 10% in the Late Baodun to being present in 18% during the Shi'erqiao. Its numbers are, however, still lower than foxtail millet.

Other plants that may have been used as food sources, however, appear to have followed a different trajectory. Job's tears, although having an ubiquity of over 20% in the early Baodun period, drops to less than 5% during the late Baodun and disappears during the Sanxingdui period. They are represented by only a few finds during the Shi'erqiao. As the finds of Job's tears during the first two phases all come from two sites (Baodun and Zhonghai) it is difficult to tell the degree to which the use of this resource, or its presence in the assemblage as a weed is due to local ecological conditions or practices.

The Shi'erqiao period is marked by a number of other important changes in the composition of food resources. Three new cultigens appear in the diet during this period of time: soybean and the western domesticates wheat and barley. The ubiquity of soybean is slightly higher (5%) than the other two. Wheat and barley caryopses are relatively rare in the assemblages we examined from the Chengdu Plain, and when present they are represented by a small number of poorly preserved caryopses.

An analysis of the proportions of different cereal crops was also carried out and showed the following patterns:

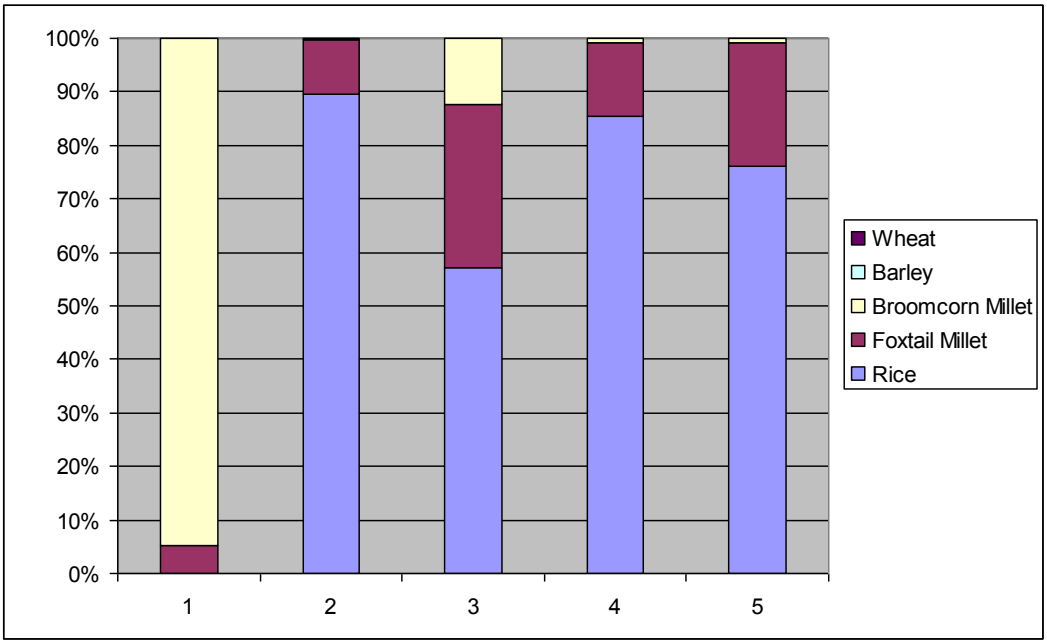

Figure 8.4 Proportions of crops on the Chengdu Plain according to phases. Phase 1= Guiyuanqiao 2=Baodun Phase 1+2,3= Baodun phase 3+4; 4=Sanxingdui; 5=Shi'erqiao

Caryopses of rice were by far the most numerous of all cereal crops on the Chengdu Plain, ranging from 89% of the total cereal crop assemblage to 76 percent of the total seed crop during the Shi'erqiao. Foxtail millet has the second highest proportion out of all cereal crops, ranging around 10-30% of the assemblage. During the late Baodun phase, the proportion of rice falls to 57% and foxtail millet increases to 30%. The percentage of broomcorn millet also increases during this period, from being almost negligible to forming over 12% of the assemblage, hinting at an increased exploitation of dryland crops. Proportions of rice rise again during the Sanxingdui and Shi'erqiao periods. Foxtail millet stays in use and forms 14% of the total cereal assemblage during the Sanxingdui period and 23% during the Shi'eriqiao period. During the Shi'erqiao period, both wheat and barley appear, albeit in very small quantities (5 caryopses each) (Table 8.3).

Table 8.3 Total counts for cereal crops unearthed in the Chengdu Plain.

	Guiyuanqiao	Baodun Early	Baodun Late	Sanxingdui	Shi'erqiao
Rice	0	930	597	326	7952
Foxtail Millet	10	104	319	53	2421
Broomcorn Millet	178	2	128	3	76
Barley	0	0	0	0	5
Wheat	0	0	0	0	5

Table 8.4 Proportion of crops unearthed from the Chengdu Plain

	Guiyuanqiao	Baodun Early	Baodun Late	Sanxingdui	Shi'erqiao
Rice whole +frag / total cereal	0	0.89	0.57	0.87	0.76
Foxtail Millet/ total cereal	0.05	0.10	0.30	0.14	0.23
Broomcorn Millet (ct)/total cereal	0.94	0.001	0.12	0.008	0.0072
Barley (ct)/ total cereal	0	0	0	0	0.0004
Wheat (ct)/ total cereal	0	0	0	0	0.00047

Given their similar size range, it is expected that wheat and barley show similar patterns to rice in terms of their survival of the carbonization process, hence it is unlikely that the very low numbers of these western domesticates are due to preferential preservation. The low ubiquity of wheat and barley could be due to several other cultural and environmental factors. That is discussed in Chapter 9.

8.3.2 Pulses

Other chronological changes occurred in the composition of the crops used by the inhabitants of the Chengdu Plain. As mentioned in Chapter 7, two main species of pulses were exploited by the inhabitants of the plain: the small seeded vetch (*Vicia* sp.) and *Vigna* sp. The poor preservation of most of the cotyledons in the assemblages from the Chengdu plain meant that it was difficult to identity the species of the *Vigna* present in the assemblages. For most of the examples unearthed where we were not able to observe a hilum or a plumule. However, on the few examples we were able to observe a plumule, these all appeared to be short. Although impossible to confirm, this leads us to believe that these may have been *V. angularis* (Adzuki bean). Our specimens are all small and fit into the range for wild adzuki bean. Studies by Crawford and Lee (2003) on the Korean peninsula found that wild Adzuki bean measured under 3mm in length and 2mm in width. The samples of *Vigna* sp. from the Chengdu plain all fit into this size range indicating that they were probably wild (Figure 8.5).

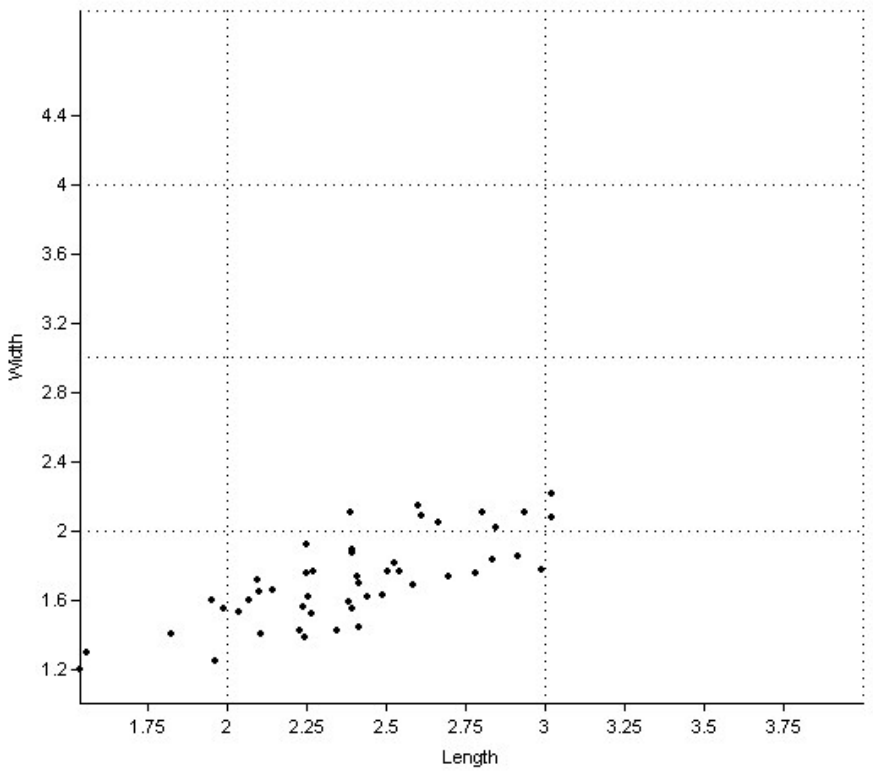

Figure 8.5 Measurements of *Vigna* sp. from the Chengdu Plain. All phases combined.

Although it has been hypothesized that Adzuki bean was first domesticated in Japan (Han, et al. 2005; Isemura, et al. 2007; Vaughan, et al. 1999; Xu, et al. 2000; Xu, et al. 2008; Yamaguchi 1992; Zong, et al. 2003), the exploitation of wild members of this species indicates that there could have been more than one center of domestication. There is strong evidence to indicate that *V. angularis* was domesticated in Japan (Crawford 1992), however, some genetic studies suggest a possible center of diversity in Nepal, Bhutan and the general Himalayan region (Xu et al. 2008; Han et al. 2005). The lack of archaeobotanical work in this area makes it difficult to establish

whether this are could have been a second center of domestication. As such, the find of possible *V. angularis* specimen provides a tantalizing piece in the puzzle of this species use.

In addition to potential Adzuki bean, one specimen of a small mung bean (*V. radiata*) was found in layers associated with Han dynasty (206 BC-220 AD) remains at Baodun. The small size of this specimen makes it possible that this specimen was wild or immature. Wild *V. radiata* are found throughout the Eastern Ghats of the Indian subcontinent and Western Himalayan foothills (Fuller and Harvey 2006). It is unclear whether or not Sichuan fits into this wild range, although given its proximity that is likely.

The analysis of ubiquity revealed that *Vicia* sp., which as we have argued could have been consumed as a food resource (see discussion in Chapter 7), is consistently present in samples from the Chengdu Plain. Its ubiquity ranges between 20-30%, with a visible decrease during the late Baodun. *Vigna* sp. also increase in numbers throughout time. Starting at less than 1% in the Baodun period, these beans steadily rise in ubiquity to just under 20% during the Shi'erqiao period. During the Shi'erqiao period a new addition to the crop repertoire appears: Soybean, albeit in very small numbers (Figure 8.6).

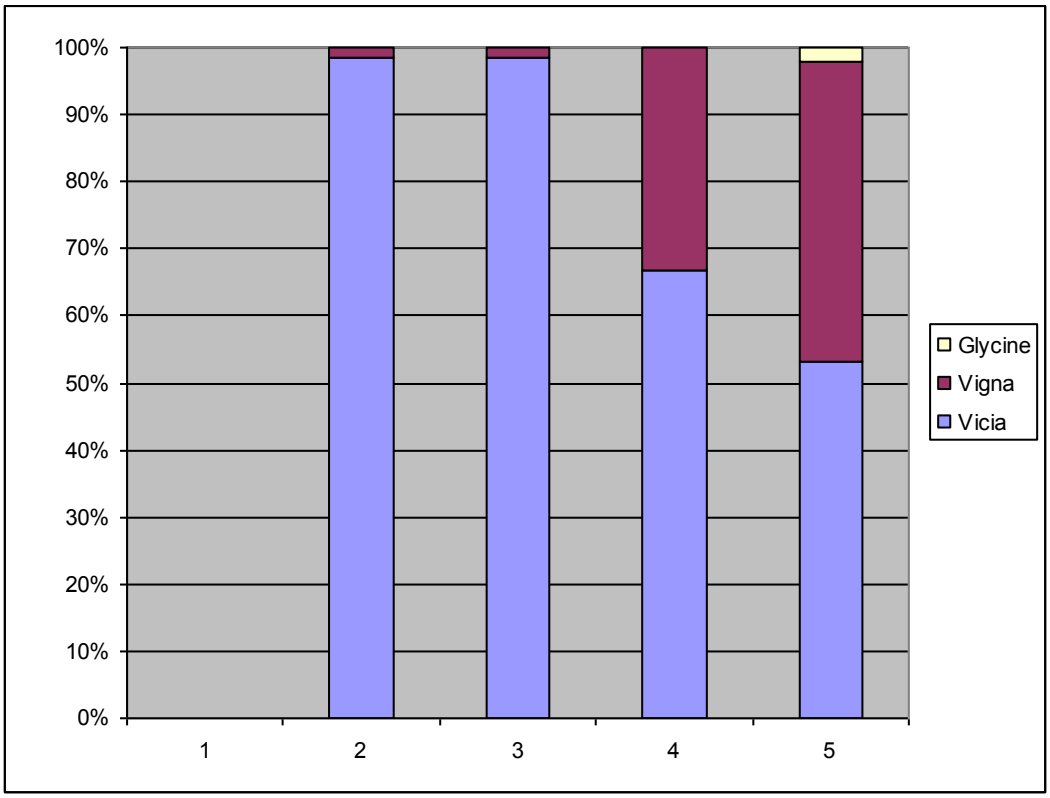

Figure 8.6 Proportions of pulses as a percentage of the total pulse assemblage. 1= Guiyuanqiao 2=Baodun Phase 1+2 ,3= Baodun phase 3+4; 4= Sanxingdui; 5=Shi'erqiao.

An analysis of the proportions of different pulses as a function of the total pulse assemblage shows similar patterns. *Vicia* sp. forms over 90% of the total legume assemblage during the Baodun period, although small numbers of *Vigna* sp. are present. Although vetch use continues during the Shi'eriqiao and Sanxingdui period, it now forms only 55% percent of the assemblage and higher numbers of *Vigna* sp. appear to be used by the inhabitants of the plain. During the Shi'erqiao period small numbers of soybean appear.

Table 8.5 Total numbers of pulses unearthed from assemblages in the Chengdu plain on a phase by phase basis.

	Guiyuanqiao	Baodun Early	Baodun Late	Sanxingdui	Shi'erqiao
Vicia (ct)/ total pulse	0	70	320	8	124
Vigna (ct.)/ total pulse	0	1	5	4	104
Glycine (ct)/ total pulse	0	0	0	0	5

8.3.3 Fruits

Kiwi fruit has also been unearthed from the site of Zhonghai. The kiwi fruit is native to China and there are 44 endemic species listed in the Flora of China (Wu, et al. 2006). Members of the genus are present from Siberia through Japan and Malaysia and Indonesia however the greatest center of diversity of the genus is found in Southwest China (Ferguson 1984). The majority of species are sensitive to frost and grow better in regions of mild frost free winters and high rainfall values. In wild form, they often grow up trees in forested areas. Relatively little is known about the domestication of the kiwi fruit, however it appears that these fruits were gathered wild until very recently. Ferguson (1984:3) mentions these being collected wild as late as 1984. The use of kiwifruit in China has been attested as early as 7000-6000 BC from the Tianluoshan site in Zhejiang Province (Fuller, Qin and Zhao 2011) as well as at early Jomon sites in Japan around 4000 BC (Stark 2006).

A number of seeds of *Sambucus* sp. (Elderberry) were also unearthed from assemblages in the Chengdu Plain. Although they may have entered the assemblage as a weed (see discussion

below), it is also possible that elderberry was consumed. Elderberry is frequently consumed in Europe and North America (Losey, et al. 2003), where the flowers and the berries are made into cordials and jams. Most of the genus *Sambucus* contain toxic glycosides in the leaves, stem and as the seeds of berries (Burrows and Tyrl 2001). The consumption of raw elderberrries can lead to stomach upset in many individuals (Turner and Szczawinski 1991). However, most of these toxins are degraded upon cooking. Four species are known to China, and the species *Sambucus nigra* is today cultivated for medicinal purposes (Wu, et al. 2006). The numbers of *Sambucus* appear to increase somewhat over time in the Chengdu Plain assemblages. The numbers of peach endocarp fragments also increase from the late Baodun period onwards.

Table 8.6 Total counts of fruit over time on the Chengdu Plain

Fruits	Guiyuanqiao	Baodun Early	Baodun Late	Sanxingdui	Shierqiao
Actidinia	0	0	0	1	5
Cratageus	0	1	8	1	0
Sambucus	0	1	0	2	8
Prunus	0	0	38	4	25
Vitis	0	0	0	0	3

Two major trends are apparent in this analysis. First, during the late Baodun, there appears to have been a shift in focus towards an increased exploitation of dryland crops (broomcorn and foxtail millet). Although rice regains its former levels in the Sanxingdui period and during the Shi'erqiao period, the diet appears to have become more diverse, with the introduction of wheat, barley and soybean. During the Sanxingdui and Shi'erqiao periods, differences in the use of pulses across the Chengdu Plain also occur and proportion of *Vigna* sp. increases over that of *Vicia* sp.

The evidence that a diversification of dryland crops occurred following the late Baodun leads us to ask whether or not similar patterns are reflected in the weed flora of the Chengdu Plain.

8.4 Weed Flora Assemblages and Changing Agricultural Strategies on the Chengdu Plain

To define systems of land use and cultivation practices, archaeobotanists have relied on the weed flora associated with crops (Bogaard, et al. 2005; Bogaard, et al. 1999; Charles, et al. 2003; Colledge 1994; Colledge, et al. 2005; Jones 2002; Jones, et al. 2005; Jones, et al. 1995). Wild seeds from the Chengdu Plain include species that are ruderal and colonize disturbed areas, such as abandoned or empty areas around sites, road sides, and the edges of fields. Others are weeds of cultivation, which grow alongside crops whose seeds are often collected and re-propagated with the crop the following year. Many weeds are also specific to ecological zones, and some can be used as indicator species for the types of agricultural regime practiced.

Weed flora can be particularly useful for distinguishing between wetland and upland systems of cultivation. As Marston (2010) and Rindos (1984) have pointed out, these seeds can be harvested and replanted with the crop, resulting in evolutionary pressure on the species of weed. This has led to co-evolution with specific species of crops. Weeds have a number of different characteristics that enable their continued survival in contexts managed (or disturbed) by humans. Weeds often exhibit extended seed dormancy, which allows seeds to wait for the opportunity to propagate. As a population, they will also exhibit discontinuous patterns of germination, permitting a new series of plants at different stages of maturity to be present in the landscape at a single time. Some weeds, particularly ruderals, help ensure their chances for survival by having

life cycles that are completed rapidly. In particular, an acceleration of the juvenile period is noted for many species. Some types of weeds use defensive mechanisms to ensure their survival. These often include mechanisms to deter predators or herbivores such chemical compounds, thorns or utricating hairs. Many weeds also exhibit increased photosynthesic rates and water usage, as well as tolerance of environmental and chemical extremes designed to remove them. The ability to parasitize other plants is also noted for many species of weed. Weeds that occupy fields of cultivation are often similar in size to the host crop. Once these seeds are collected alongside the host crop, their similarity in size allows them to remain alongside the host crop throughout the processes of threshing, winnowing and sieving that are designed to remove seeds of smaller-seeded species of weeds (Holm, et al. 1977; Holzner and Numata 1982). As Fuller and Stevens (2009) have pointed out, this allows large-seeded weeds to follow the host crop along the processing spectrum until re-planting or until they are handpicked out of the assemblage.

As little archaeobotanical work has been carried out in Southwest China, a careful reading of the ethnographic and agronomic literature was necessary in order to categorize the weeds found in the assemblage at Baodun into weeds inhabiting wetland or dryland environments. This analysis was carried out using regional guides to weeds for farmers (Zhang, et al. 2003; Zhou and Zhang 2006) as well as guides covering the whole of China (Wang 1990). In addition, I consulted modern studies of weed management (National Study Group of Field Weeds 1988a, b; Qiang and Li 1989; Tang 1988; Tang and Wang 1988; Zhang and Zhang 1999; Zhou, et al. 1999). For eastern and Southeast Asia, a number of excellent guides to weeds, in particular those of rice paddies, also exist (Bhagat, et al. 1996; Holzner and Numata 1982; Moody 1989; Musil 1963; Raju 1999; Soerjani, et al. 1987).

We classified common weeds found in the paleobotanical assemblages of the Chengdu Plain into several different categories: wetland weeds, dryland weeds, and weeds common to both wetland and dryland. For dryland weeds, we noted when a weed was also a ruderal species (see Appendix E).

8.4.1 Weeds of wetland environments

Members of the sedges (Cyperaceae) family are weeds that are often found in wetland environments, although many members of this family can also occupy dryland environments (Bryson and Carter 2008). As a result, it was necessary to take care in identifying the members of the Cyperaceae family in assemblages from the Chengdu Plain. Sedges reproduce through the production of large numbers of small achenes, whose small size makes them difficult to detect in soils and the products of harvest.

A member of the sedge (Cyperaceae) family, *Fimbristylis* sp., was very highly represented in assemblages from early Baodun period deposits. This species of *Fimbristylis* most closely resembles *F. dichotoma*. Achenes of this species were recovered mostly in the form of silicified achenes: The high silica content of these achenes mean that they rarely char. *F. dichotoma* is reported as being a common weed of paddy rice or wetland environments and it thrives in these environments thanks to its ability to grow well in poorly aerated and partially submerged soils (Li 1984; Raju 1999; Soerjani, et al. 1987; Wang 1990). *Fimbristylis dichotoma* and F. *miliacea* are co-ranked as the world's 40th worst complex of weeds and cause huge damage to rice fields around the world (Holm et al., 1977).

Other members of the genus Cyperaceae were also found in samples from the Chengdu Plain. Members of the genus *Scirpus* are not as prolific producers as the genus *Fimbristylis* (Bryson and Carter 2008), however, they are noted as weeds of rice in several guides to weeds in China (Wang 1990). Charred *Scirpus* achenes as well as charred achenes of *Carex* sp. were also recovered from the assemblages on the Chengdu Plain. Twelve different species of *Carex* are listed as weeds of wetland and paddy environments in China (Wang 1990). Their longer life cycle and lower production of achenes means that in contemporary situations they do not form invasive weeds. A few achenes of the genus *Cyperus* were also found in our samples. Weeds of different species of the genus *Cyperus* are today notorious weeds of rice paddies. Their annual habit, rapid growth, short generation time, high fecundity, and tolerance of submergence of roots have enabled species such as C. *difformis* and *C. iria* to persist and disperse as weeds of rice together with which they likely evolved these characteristics (Bryson and Carter 2008).

A number of members of the Poaceae family, which are known to be weeds of wetlands environments, were found in samples from the Chengdu Plain. This includes, in a few samples, large numbers of *Miscanthus* sp. caryopses. One species of *Miscanthus* is listed by Wang (1990) as being a weed of paddy field sides, however other species are listed as occupying dryland environments, however, making it difficult to classify this weed. Other species of wetland weeds that were found in the assemblages of the Chengdu Plain include cross sections of the stem of the living fossil horsetail or *Equisetum* sp. Of the 10 species of *Equisetum* known from the Flora of China, most of these prefer wet soils and some are adapted to wetland environments (Wu, et al. 2006).

Another well known weed growing in wetland environments is the perennial aquatic plant Pondweed (*Potamogeton* sp). Twenty species are present in China, and all occupy wetland environments (Wu, et al. 2006). Pondweed can quickly occupy rice paddies and can be a considerable pest (Holm, et al. 1977; IRRI 1981). A few examples of pondweed were unearthed from the assemblages of the plain. Job's tears, which we discussed as a possibly cultivated crop, was also noted as a weed of irrigated lowland rice in an ethnobotanical study carried out by Weisskopf et al. (2010), and wild species are described in the Flora of China as occupying moist areas surrounding paddy fields (Chen and Phillips 2006).

8.4.2 Weeds of Dryland Environments

A number of weeds associated with dryland environments were also uncovered in the assemblages from the Chengdu Plain. Wild members of the *Setaria* complex are common weeds in fields of foxtail millet. Their close relation to foxtail millet means that members of this complex share many of the same characteristics that allow for continued propagation and co-evolution alongside domesticated species. Because of similarities in appearance and the timing of reproductive cycles, seeds of wild *Setaria* are often harvested and consumed along with the crop, and subsequently re-planted (Henri 2005). In addition, the transfer of favorable genetic traits between the cultivar foxtail millet and wild members of the genus *Setaria* has allowed these weeds to create a niche opportunity for their survival and continued propagation. Carefully timed patterns of dormancy also allow seeds of this genus to maintain a soil seed bank which is viable for many years, ensuring their continued occupation of a patch of the landscape (Dekker

2004). Wild forms of *Setaria* are also known to occupy fields of other dry-field crops, like wheat and barley (Dekker 2004).

Other members of the Poaceae family, which are common weeds of dryfield crops and which were found in these samples, include: *Digitaria* sp. (Wang 1990), *Hackelochloa* sp, and *Eleusine indica*. Two species of *Hackelocloa* are native to China (*H. granularis* and *H. porifera*). We were not able to distinguish between the two species on the basis of morphology, however. The Flora of China lists only two species of *Eleusine* in China. *Eleusine indica* may be native to China, however the closely related *Eleusine coracana* is introduced (Wu, et al. 2006). *Galium* sp. is a well known weed of dryland crops in Europe and the Near East (Cappers and Raemaekers 2008; Fuller 2007; Marston 2010), and it is likely that it also occupied fields of millet and other crops in southwest China (Wang 1990; Zhou and Zhang 2006).

Other weeds of dryland environments found in the assemblage include members of the Solanaceae family, such as *Solanum* sp. and *Hyoscamus* sp. (Wang 1990; Zhou and Zhang 2006). Members of the Caryophyllaceae family also occupy dryland environments. A number of seeds from small shrubs occupying dryland environments were also present in the assemblages. These include members of the genus *Verbena* sp. Only two species of *Verbena* sp. are known in China and include the common vervaine, which is commonly used as a herbal tea in traditional Chinese medicine (Hunan Sheng Yiliao Yanjiusuo 1977).

A number of seeds from the elderberry shrub *Sambucus* sp., which occupies disturbed land, were also found in the assemblage. As discussed above, however, these could also have been consumed by the inhabitants of the site.

A number of other plants that occupy dryland environments are ruderal species, which occupy disturbed land. These include *Chenopodium* sp. which is a well known disturbance taxa indicator (Holzner and Numata 1982). *Chenopodium* sp. is a weed common to many dryland agricultural fields in China and across the world today (Wang 1990). It has also been argued that *Chenopodium* sp. may have been consumed in China (see discussion in chapter 6) (Xue 2010; Yang and Liu 2009; Zhao and Chen 2011). Other possible dryland disturbance taxa may also include the small vetch, *Vicia* sp., which we have argued (see discussion above) may have been cultivated or foraged for its edible leaves and seeds. Other species that may have been consumed include members of the Brassicaceae family.

8.4.3 Weeds Occuring in both Dryland and Wetland Environments

We were not able to classify a number of the weed species found in the archaeobotanical assemblages on the Chengdu Plain into occupying either wetland or dryland environments. This was either because these weeds occupy both ecological zones, or because we were not able to identify these members to a level where they were indicative of ecological zones.

Families of weeds whose members contained both dryland and wetland weeds included the members of the genus *Polygonum*. These are also known to inhabit both wetland and dryland environments. Large numbers of charred *Echinocloa* sp. caryopses were unearthed from the Chengdu Plain. Two different species of *Echinocloa* are listed by Wang (1990) as being common weeds. These are *Echinocloa crusgalli* that is well known for being an invasive weed of paddy environments in China (Baltazar and Smith 1994; Gibson, et al. 2002; Michael 1978; Moody 1989; Raju 1999; Soerjani, et al. 1987; Tang 1988; Wang 1990) and *Echinocloa colona* that is a

common weed of upland or rainfed rice in Southeast Asia. Species of *Echinocloa* can cause large damages to rice crops because of their ability to alleopathically inhabit the germination of rice seedlings (Duong, et al. 2010). In Southeast Asia, species of *Echinocloa colona* are reaped alongside the rice harvest and consumed by humans and by animals as fodder (Catindig, et al. 2012). Because of the high degree of morphological similarity between different species of *Echinocloa* we were not able to identify our specimens of *Echinocloa* down to the species level and as a result additional analyses is needed to confirm whether or not the species of *Echinocloa* found in our samples are associated with a dryland or a wetland environment.

Xanthium sp. is a weed that is described as colonizing moist areas of dryland environments (Wu, et al. 2006). It cannot grow in poorly aerated soils or partially submerged conditions, but is often found in disturbed areas that border rivers (or paddy fields) (Marston 2010) making it difficult to determine if a given specimen grew in a wetland or dryland environment. We also included taxa we were not able to identify down beyond the family level as members of the Cyperaceae family.

8.4.4 Results of the analysis of weed flora

I divided different species into the categories of dryland and wetland weeds, and created a third category, that is, weeds that are common to both wetland and dryland environments.The total upland and dryland weeds represent weeds that we were not able to identify to a level of specificity that we could assure which environment they inhabited, or were from species that are known to inhabit both, such as *Echinocloa* sp. An analysis of the total assemblage of weeds by time period was carried out, excluding for the samples from Guiyuanqiao phase 1. We recovered only 2 samples from this period as well as a very small number of weeds, so we could not carry

out this analysis. However, given the nature of domesticates consumed at Guiyuanqiao phase I, it seems likely to assume that these would have been dominated by dryland weeds.

An analysis of the ubiquity of wetland and dryland weeds on the Chengdu Plain revealed several interesting patterns. When examined on a phase by phase basis, some changes are apparent between the Baodun, Saxingdui and Shi'erqiao phases. Deposits dating to the Early Baodun contain the highest ubiquity of wetland weeds and are largely dominated by *Fimbrystilis* sp. and *Equisetum* sp. Some wetland weeds disappear completely from the assemblage during the late Baodun including *Potamogeton* sp., *Equisetum* sp. and *Cyperus* sp.

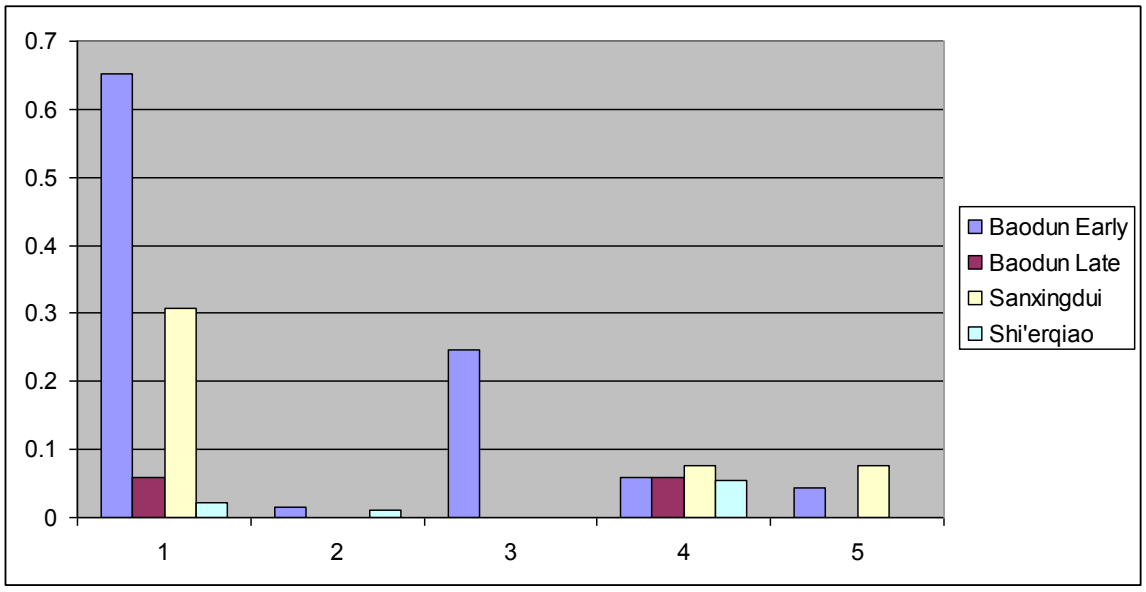

Figure 8.7 Ubiquity analysis of wetland weeds from the Chengdu Plain. 1) *Fimbrystylis* sp.; 2) *Potamogeton* sp.; 3)*Equisetum* sp. ; 4) *Scirpus* sp. ; 5)*Cyperus* sp.

An analysis of dryland weeds revealed a slightly different pattern. The numbers of wild *Setaria* sp. appear to have remained relatively consistent throughout time (Figure 8.8, Taxon #1). *Galium*

sp. appears to increase during from the Early Baodun to the Sanxingdui period, however its numbers drop again during the Shi'erqiao period (Figure 8.8, Taxon #2). *Hackelocloa* sp. is only present during the early Baodun period (Figure 8.8, Taxon #3). The ubiquity of *Eleusine indica* rises during the late Baodun and decreases again during the Shi'erqiao period (Figure 8.8, Taxon #4). The ubiquity *Digitaria* sp. is higher during the Early and Late Baodun and decreases subsequently (Figure 8.8 Taxon #5). For Brassicaceae, Asteraceae, *Oxalis* sp., Portulaceae, Malvaceae and Ranunculaceae, the ubiquities of these taxa increase somewhat between the early and late Baodun (Figure 8.8, Taxon #8-13). *Agrostis* sp. is only present during the late Baodun and Lamiaceae members are also only present during the Late Baodun and Shi'erqiao periods, as are *Stachys* sp. and *Stipa* sp (Figure 8.8, Taxon #18-19).

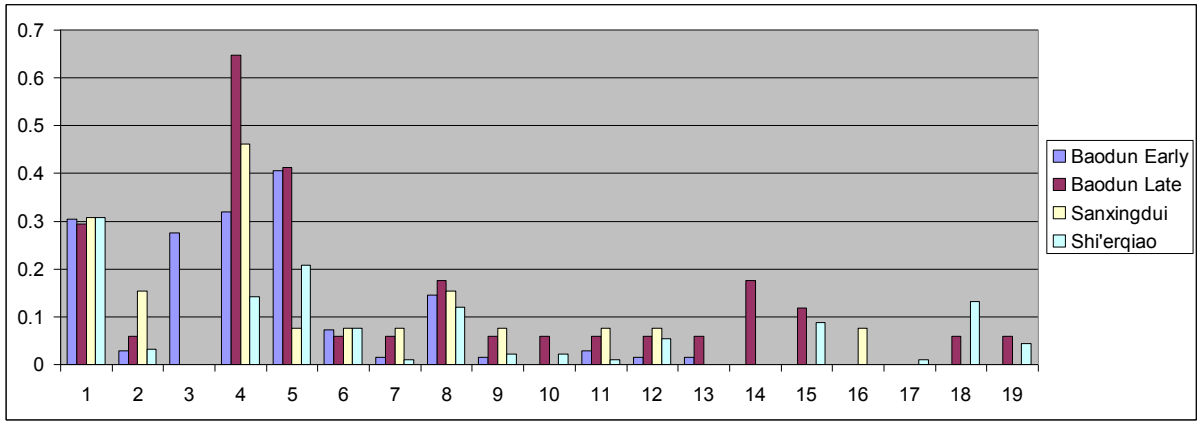

Figure 8.8 Ubiquity analysis of dryland weeds from the Chengdu Plain. 1) *Setaria* sp. 2) *Galium*; 3) *Hacklecloa*; 4) *Eleusine indica*; 5) *Digitaria*; 6) Solanaceae; 7) Caryophyllaceae; 8)Brassicaceae; 9) Asteraceae; 10) *Oxalis*; 11) Portulacaceae; 12) Malvaceae; 13) Ranunculaceae; 14) *Agrostis*; 15) Lamiaceae; 16) *Phytolacca*; 17) Umbelliferae; 18) *Stachys*; 19) *Stipa*

I examined the proportion of wetland and dryland weeds as a function of the total weed seed assemblage, revealing some interesting patterns (Figure 8.9). High proportions of wetland weeds are only present during the early Baodun phase, after which they are almost entirely by dryland weeds. During the late Baodun, large numbers of weeds that could be attributed to either category were present. The assemblage from the Sanxingdui period is dominated by dryland weeds, however, during the Shi'erqiao period the proportion of weeds that we could not be attributed to either environment increased. This change in the composition of wild seeds could be due to several different factors. Firstly, it is possible that dryland agriculture did become more important during the late Baodun, as the analysis of crop remains seems to indicate: the proportions of both foxtail and broomcorn millet increased during this period of time. Although this pattern does not hold true for domesticates, the increase in dryland flora appears to continue during the Sanxingdui period. The over representation of dryland weeds, may, however, be due to the smaller and less diverse sample size from assemblages dating to this period as well as a small sample size (n=13). These proportions may also be skewed because of the presence of what appears to be a large cache of Brassicaceae seeds (n= 103) found at the site of Sanxingcun.

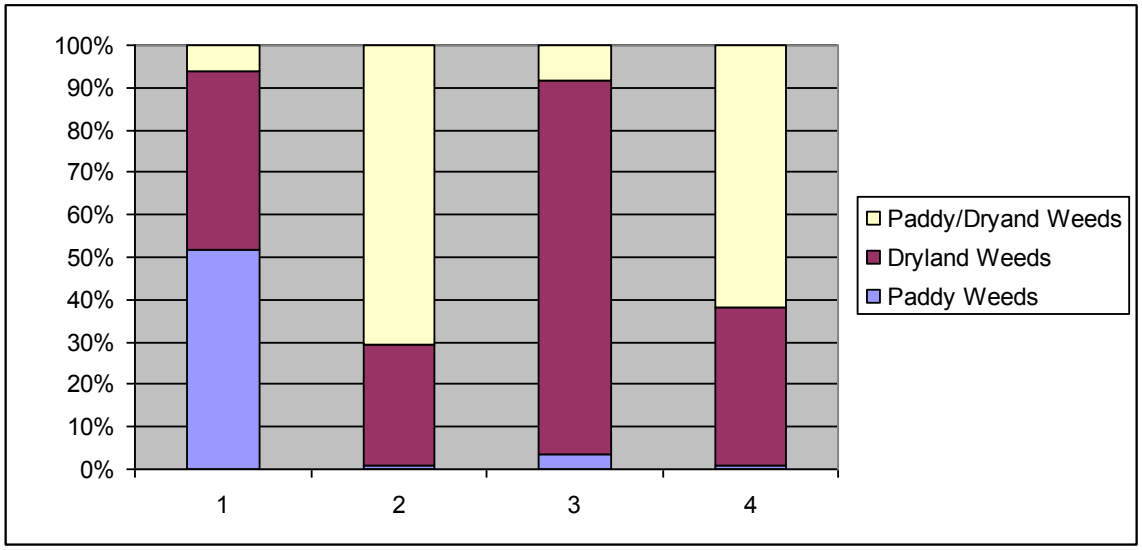

Figure 8.9 Proportions of different categories of weeds on the Chengdu Plain 1) Baodun phase 1+2; 2) Baodun Phase 3+4; 3) Sanxingdui; 4) Shi'erqiao

However, other possibilities also emerge. Despite the decrease of weeds associated with paddies over time, it is, apparent that rice still remained the primary focus of the local diet. While it is possible that this higher number of dryland weeds could be associated with an increased exploitation of dryland crops, it could alternatively be due to increased burning of disturbance taxa around the site. In addition, the decrease in weeds from paddies could also be due to more effective management of weed growth in paddies. Flooding with water suppresses the growth of many weed seeds in paddies, and removal of weeds is also carried out more intensively. Practices of transplanting young rice seedlings can also help to eliminate weed seeds. As fields are flooded only at the time that young rice plants are placed in the field, weeds are either eliminated or can be easily distinguished from the rice plants. As result, it is not entirely unexpected that the numbers of weeds associated with wetland environments was lower than for dryland environments overall. During the early Baodun phase, the majority of wetland weeds are

of the single species *Fimbryistilis*, a common weed of rice paddies today. Does the reduction in numbers of *Fimbryistlis* mean that more effective weeding practices developed between the early and late Baodun or could this truly be due to an increased focus on dryland agriculture? The large number of weeds that we were not able to ascribe to a particular environment, particularly during the late Baodun and the Shi'erqiao period, make it somewhat difficult to interpret these results.

8.5 Crop processing and Changes in Labor Organization on the Chengdu Plain

Given the marked increase in social complexity between the Baodun period and the Bronze Age, it is interesting to ask what kinds of changes in labor mobilization patterns could have occurred. A number of authors have argued that changes in crop processing strategies can help document changes in labor mobilization in prehistory (Fuller and Stevens 2009; Fuller, et al. In Press; Hillman 1981; Hillman 1984; Jones 1991; Jones and Jones 1996; Stahl 1989; Stevens 2003a, b). In order to become edible, most cereal crops have to undergo some form of processing, and the stage at which crop processing is carried out and the form in which crops are stored can allow inferences on ancient labor mobilization patterns (Fuller and Stevens 2009; Jones 1987; Jones 1991; Jones and Jones 1996; Stevens 2003a, b).

Fuller and Stevens (2009) expect that a large-scale mobilization of labor to process crops immediately after the harvest should create a punctual concentration of crop processing waste, whereas the majority of the archaeobotanical assemblage would be dominated by clean grain. On the other hand, when crops are processed on a day to day basis, the wastes of processing and weed seeds should be present in high proportions in archaeological sites. This kind of analysis

can also be useful for understanding site function. If some sites are recipients of fully processed agricultural products and other sites are shown to be the locus where crop processing is carried out this can allow us to comment on the different roles these sites played in economic organization and thus can be useful for distinguishing producer from consumer sites (van der Veen 1992).

Crop processing studies have been approached in several ways. In Bronze Age England, M. Jones (1985; 1991; Jones and Jones 1996) has attributed the patterns in proportions of weed seed and grain seen between sites as being due to differences between producers and consumers. At these sites, a pattern of either grain rich or chaff rich assemblages was seen to distinguish hillforts from smaller settlements. In his analysis of this material, Jones and Jones (1996) argued that differences in the charred assemblages reflect differences in the sites' past role in production and consumption. He reasons that within producer settlements, grain would be readily wasted, leading to grain-rich assemblages. Given that the grain-rich settlements were situated in locations more suited to arable farming he interpreted them as cereal producers. Conversely, in sites receiving grain he suggested crops would be more carefully processed, with grain less readily wasted, leading to assemblages richer in weed seeds and chaff. Settlements with charred assemblages richer in weed seeds and chaff were recovered from sites less suited for arable farming on the floodplain. This led Jones (1985) to interpret these sites as being inhabited by pastoralist grain consumers.

In a critique of this model, Stevens (2003) and Fuller and Stevens (2009) developed a model that explained the differences in the proportion of grain, chaff, and weed seeds as resulting from the

stage at which crops were stored. In particular, they argue that, as weed seeds are gradually removed at various stages of crop-processing, the ratio of weed seeds to grain within the crop declines (Fuller and Stevens; Stevens 2003). If processing waste (from routine processing after storage) is the dominant form of charred remains represented in most samples, then variation in the ratio of weed seeds to crop grain may reflect the number of processing stages the waste has undergone. If crops were stored largely unprocessed, then the waste from all the remaining stages would contain high numbers of weed seeds, but if they were stored in a more processed state, then the waste would contain far fewer weed seeds compared to the grain, as weed seeds are also lost during dehusking.

Unprocessed assemblages should thus contain higher proportions of weed seed to grain, whereas fully processed assemblages should contain lower numbers of weeds. In addition, the Fuller and Stevens (2009) and Stevens (2003; In Press) have also used the proportion of small to large weed seeds as an indicator of the stage of crop processing. The logic here is that small weed seeds are removed at earlier stages of processing, such as sieving and winnowing, whereas large weed seeds that mimic the size of the grain will only be removed at later stages in processing, namely hand picking. All of these studies assume that most archaeobotanical deposits on a site are the result of routine daily activities and not the result of discrete events (such as accidental burning of a house or a store of grain). Any samples that appear to result from discrete events should, as a result, be dropped from any analysis.

Only two studies of crop processing have been carried out in China, and they have both focused primarily on millet agriculture. One is a study carried out on samples derived from survey in the

Ying River valley in Henan (Fuller and Zhang 2007), the other is Song Jixiang's (2011) doctoral work in Shandong. For millet processing, the proportion of immature millet grains to mature grains and hulled grains to unhulled grains is argued to be an important factor for distinguishing fully processed from unprocessed assemblages (Fuller and Zhang 2007; Song, et al. 2012). In millets, immature grains are removed along with other by products after threshing and winnowing, hence their proportions can be useful in looking at crop processing. Using the hulled versus non-hulled as a criteria is however, problematic as the survival of hulls can also largely be due to firing temperature. In their study of the material from Shandong (Song 2012) and the Ying River valley material, Fuller and Zhang (2007) also use the total proportion of weed seeds to millet. In her study of millet crop processing, Song (2011) suggests that several other criteria may be useful in considering how processed a given crop was. She argues that the quantity of weeds may be affected by harvesting height and that one can distinguish between weeds entering the assemblage as a result of other processes and weeds entering the assemblage as a result of harvesting because they were of a similar height to the crop being harvested.

Although this has not been tested against macrobotanical data, Harvey and Fuller (2005) have created a schema for describing the different crop processing stages associated with rice. This schema is informed by previous ethnographic studies carried out by Thompson (1996) carried out in three villages of lowland Thailand. According to Thompson (1996), the basic sequence of rice processing operations is similar to that of glume wheats and includes harvesting, threshing, and winnowing. But in the observed ethnographic case, after winnowing, rice was put into bulk storage with their husks intact while wheat was further sieved to remove straw nodes, weed seeds, etc. Only after being taken out of storage was rice pounded to remove husks and then winnowed

again. By looking at the proportions of rice grains to spikelets it should thus be possible to see if rice grains were stored in a more or less processed form or hulled vs. non-hulled form.
Using weed flora as an indicator of crop processing stages in rice is problematic. In particular, rice fields will often contain less weed contaminants than other kinds of fields because many species in the soil seed bank will be drowned out by the water required for paddies (Harvey and Fuller 2005; Thompson 1996). In addition, rice reaping also appears to be primarily focused on the panicles in rice harvesting practices therefore harvesting practices could also have reduced the numbers of weeds present in an assemblage. Harvey and Fuller (2005) nonetheless suggest that the proportion of light to heavy weed seeds can be used as a criteria to indicate the degree of crop processing as lighter weeds are removed in the initial stages of winnowing and heavier seeds are removed at the stage of hand picking (see Harvey and Fuller (2005:Fig. 3)).

Critiques of crop processing models argue that it is difficult to distinguish between weed seeds that have entered the archaeological site because they are disturbance taxa (i.e *Chenopodium* sp.) and weeds that are truly weeds of cultivation (Chen 2009). Similar problems occur with differentiating between seeds from plants that functioned as weeds in the true sense and plants that may have been consumed, such as *Vicia* sp. In addition to being complicated by trying to identify which species are weeds of cultivation and which entered the assemblage through other means, the study of crop processing on the Chengdu Plain is further complicated by the fact that two different staple crops were grown by the inhabitants of the plain. Rice and foxtail millet are very different in size and therefore we need different criteria for the size of weeds that would have accompanied each crop**.** In addition, we were not able to concretely ascribe a large number of the "weed" taxa on the Chengdu to either a wetland or a dryland environment, making it

difficult to understand which weeds were brought in alongside rice harvesting and which were brought in alongside millets. It thus was not possible to approach the issue of crop processing on the Chengdu Plain using data on weed taxa.

Two different kinds of data could be brought to bear on this question: 1.) The ratio of rice spikelets to rice grain, 2.) the ratio of rice embryos to rice grain as is indicated by Harvey and Fuller (2005). Rice spikelets will be removed in the final stages of crop processing. As a result, their presence on a site should indicate that crop processing took place on a daily basis. Although rice can be consumed with the nutrient rich embryo attached, the embryo is often removed to improve taste and to extend storage life. Large numbers of rice embryos were found in the assemblages on the Chengdu plain, and we can use these as another statistic to indicate how processed crops were. Both rice spikelets and embryos are revealing of the final stages of crop processing, hence their presence/absence may only indicate if the final stages of crop processing were carried out at the site. Their absence may suggest that crops were fully processed immediately following the harvest. However, the caveat here is that they cannot tell us about whether or not the earlier stages of crop processing were carried out at the site.

I first carried out this analysis on a site by site basis.

Table 8.7 Numbers of rice grains, rice spikelets and embryos and ratios of rice grain to rice spikelet and rice grain to rice embryo

	No. of rice grains	No. of rice spikelets	No. of rice embryos	Rice grain to embryo ratio	Rice grain to spikelet ratio
Baodun	930	1233	181	5.13	0.75
Sanxingcun Baodun	31	44	1	31	0.70
Sanxingcun Sanxingdui	74	61	37	2	1.21
Zhonghai Baodun	317	2797	156	2.03	0.11
Zhonghai Sanxingdui	152	1324	29	5.24	0.11
Qingchenjian	922	2572	90	10.24	1.43
Bolocun	2814	7907	630	4.46	0.35
Taipingcun	148	347	25	5.92	0.42
Yongfucun Baodun	20	11	0	0	1.81
Yongfucun Bronze Age	413	340	0	0	1.21
Zhujiacun	241	1006	302	0.79	0.23
Yantangcun	2046	1069	320	6.39	1.91
Huayuan Baodun	229	9	8	28.62	25.4

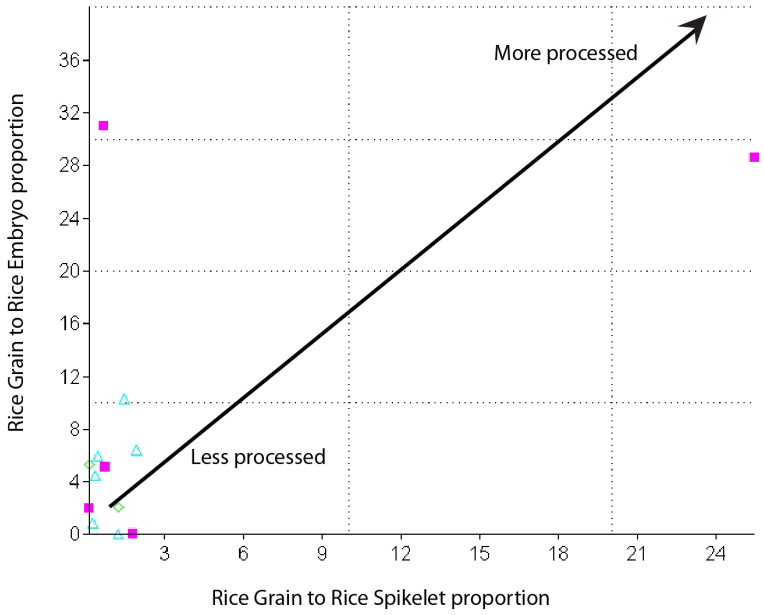

Figure 8.10 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing. Higher numbers indicate that there is a higher proportion of rice grains to spikelets and rice grains to embryos. Pink square= Baodun period site, Green diamond= Sanxingdui Period site, Blue triangle= Shi'erqiao period sites.

The analysis on a site by site basis shows that the Baodun components at the site of Huayuan contain the most processed assemblage and the highest proportions of clean grain. The Baodun components at Sanxingcun also contain a very small number of embryos. All other sites cluster around the lower end of the processing scale. Unlike rice spikelets, rice embryos were found only in very low ratios and in general rice grains are between 1 -30 times more numerous than rice embryos. The overall lower numbers of rice embryos is not surprising as some of these may have been left on the grain and consumed by inhabitants of the site (Figure 8.10).

If we remove these two highly processed samples, and look at the graph then the following pattern emerges (Figure 8.11)

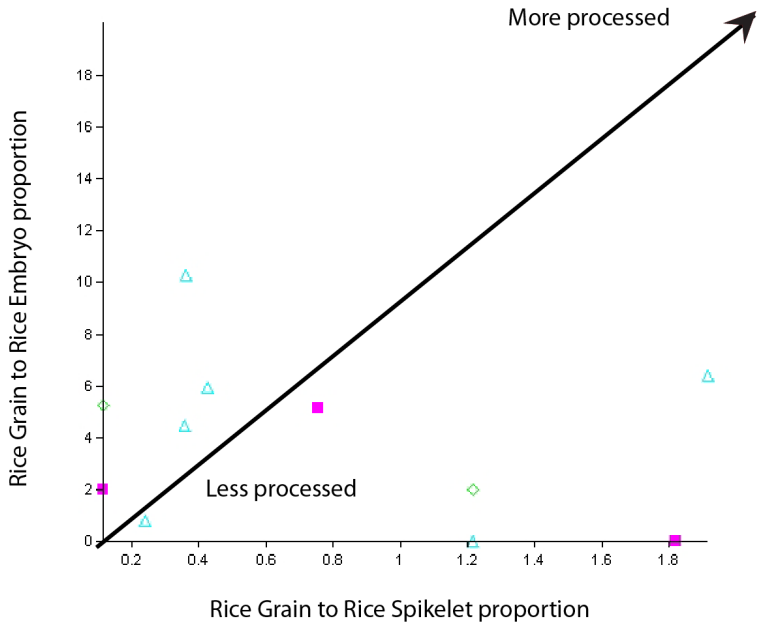

Figure 8.11 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing. Higher numbers indicate that there is a higher proportion of rice grains to spikelets and rice grains to embryos. Pink square= Baodun period site, Green diamond= Sanxingdui Period site, Blue triangle= Shi'erqiao period sites.

Here Yangtangcun contains the most processed assemblage, followed by Yongfucun (both Baodun and Shi'erqiao components). On the other hand, very high proportions of crop processing waste were found at the sites of Zhonghai and Zhujiacun followed, by the site of Baodun itself. No patterning according to time period was visible in these samples.

In addition, no clear connection between specific assemblages and between specific types of sites (i.e., large walled sites or smaller settlements) becomes apparent. The pattern seen in a site by site analysis suggests that different sites may have received grain in more or less processed states, or that the inhabitants of these sites processed grain at some central location off site and then brought it back to the site in a relatively processed state. In order to say whether or not this impression is true, it is essential to demonstrate that samples within a site were homogenous in terms of how crop processing remains were distributed. I thus also decided to carry out this analysis on a sample by sample basis (Figure 8.12).

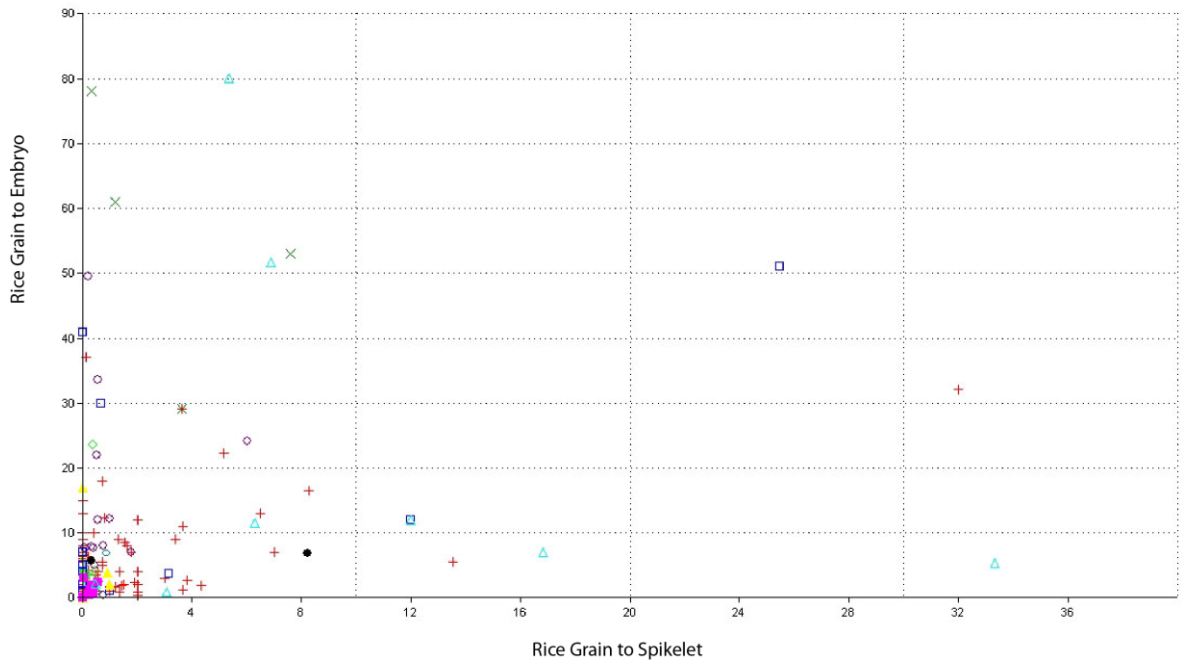

Figure 8.12 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing. Higher numbers indicate that there is a higher proportion of rice grains to spikelets and rice grains to embryos. Red cross= Baodun period samples from Baodun; light blue inverted triangle= Zhonghai Baodun period sample; Grey fill diamond= Zhonghai Sanxingdui period sample; Green triangle= Bolocun; purple circle= Qingchenjian; Turquoise oval=Yongfucun Baodun period; Blue square= Huayuan Baodun period; Yellow filled Triangle= Sanxingcun, Sanxingdui period; Black dot=Taipingcun Shi'erqiao Period; Green cross=Yongfucun Shi'erqiao period; Pink filled square=Zhujiacun Shi'erqiao period; Turquoise triangle=Yantangcun.

When combining all samples and all time periods, it becomes apparent that there was a high degree of variability between different samples from a given site, and while some samples contained high proportions of clean grain, others were dominated by crop processing waste.

Samples at Huayuan were overall more processed than those from other sites, however, the majority of samples were still clustered closely around the lower end of the processing scale, indicating that at all of these sites rice was likely stored in husks.

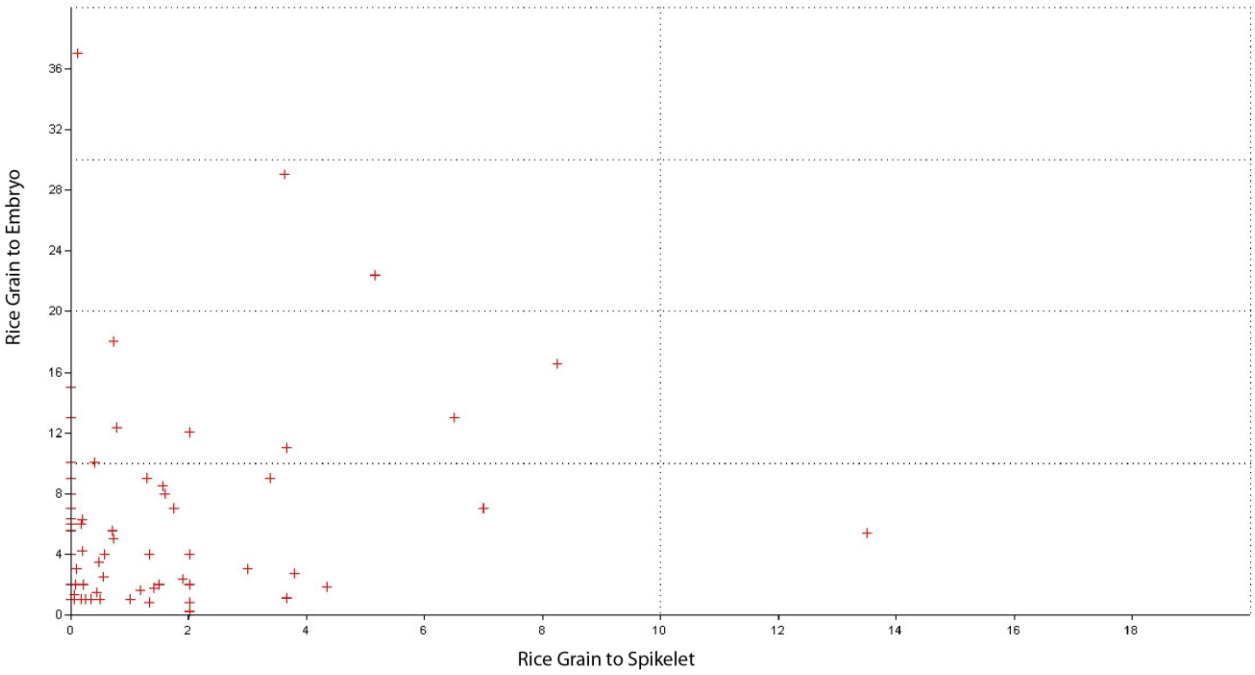

Figure 8.13 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing using samples from the site of Baodun. Higher numbers indicate that there is a higher proportion of rice grains to spikelets and rice grains to embryos.

For instance, if we look at samples across a single site, it becomes apparent that rice spikelet bases were either equal to grains in rations or were higher than the number of grains for many samples, allowing us to conclude that risk was stored in husks at the site and processed routinely. However, some samples clearly deviated from this pattern and contained cleaner grain (Figure 8.13).

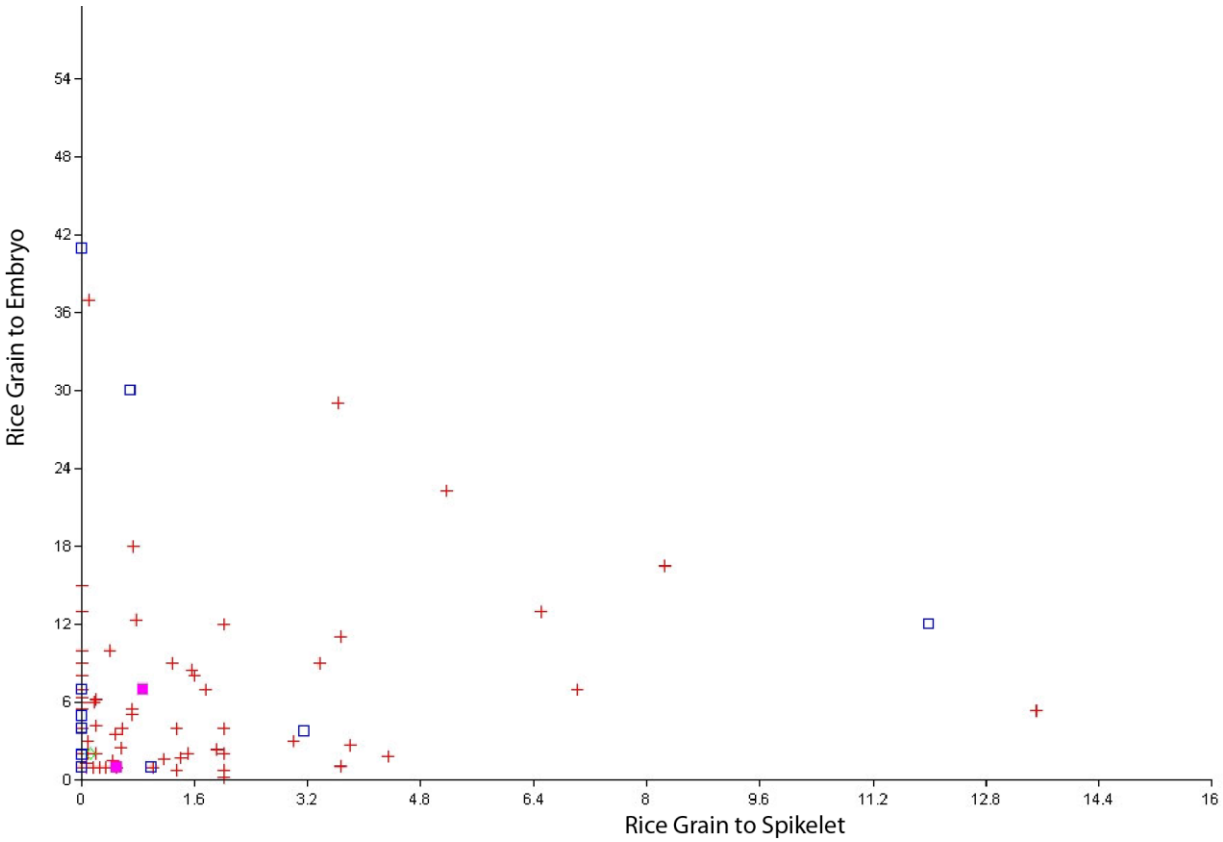

Figure 8.14 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing using samples from the site of Baodun=Red cross; Pink square=Yongfucun; Blue square=Huayuan; Green Triangle= Zhonghai. Higher numbers indicate that there is a higher proportion of rice grains to spikelets and rice grains to embryos.

I also decided to carry an analysis of crop processing on the basis of time period (Figure 8.14). If we compare the patterns at the site of Baodun to those from other sites dating to this period there is a high degree of variability within samples from a given site. In addition, no sites relating to this period show patterns that are distinct from others. The majority of samples contain high numbers of rice spikelets and embryos and constituted the remains of the final phases of crop

processing, indicating that rice was stored with husks intact and processed on site on a daily basis. Despite this, at each site a number of samples were present that consisted of relatively clean grain. It thus became apparent that not all the archaeobotanical assemblages on the Chengdu Plain were the result of routine activities. Some were the result of discrete events that led to the accidental (or other) burning of clean grain via discard of store of rice that had gone bad, or the burning down of a house, or other such event.

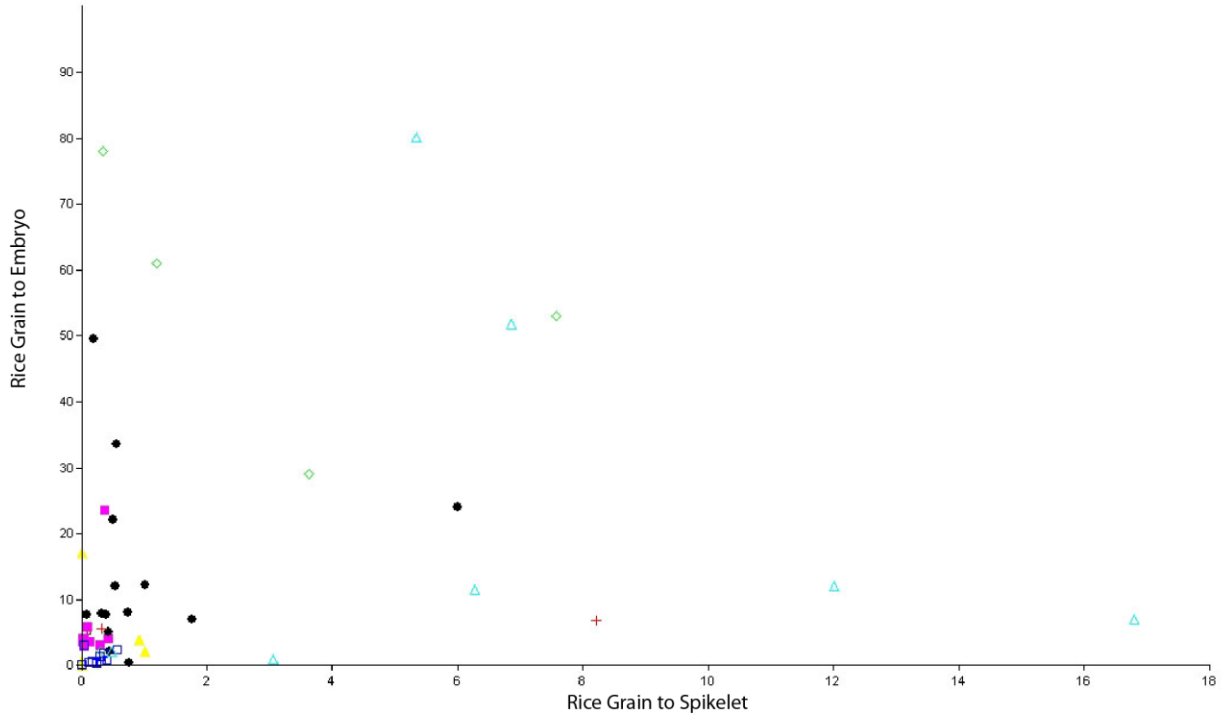

Figure 8.15 Plot of the proportions of rice grains to rice spikelets and rice grain to rice embryo as an indicator of the degree of crop processing using samples from Bronze Age sites. Pink square=Bolocun; Black dot=Qingchenjian; Yellow Triangle=Sanxingcun Sanxingdui period, Turquoise Triangle=Yantangcun; Blue square=Zhujiacun; Taipingcun=Red Cross; Green Diamond=Yongfucun; Maroon Line=Zhonghai Sanxingdui period sample.

An analysis of samples from the Bronze Age (Figure 8.15) revealed a similar pattern. While some samples were composed of relatively clean grain, others contained high numbers of spikelets. Some samples were clearly composed of routine discard of crop processing waste, however others appear to have been formed accidentally.

Through this study of crop processing on the Chengdu Plain, I was not able to document changes in crop processing activities either between sites or changes over time. Within single time periods and across time periods, it appears that the final stages of crop processing (i.e, removing the rice from its husks) was routinely carried out at sites in the Chengdu Plain, indicating that crops were stored in a hulled state. However, some samples indicate that stores of processed grain were also discarded at the sites.

In order to understand if differences in labor organization related to crop processing took place over time or between different types of sites on the Chengdu Plain, it would be necessary to carry out an analysis of the proportion of light to heavy weed seeds. However, in order to do so it is first necessary to make sure the weed seeds in the assemblage are indeed associated with archaeological rice paddies and not dryland fields, and did also not enter the assemblage because of their role as disturbance taxa around sites. To do so, it would be necessary to refine identifications of many of these seeds. Future research on refining identification criteria for weeds in southwest China will help resolve this issue. I was not able to confidently carry out such an analysis for this dissertation because the state of preservation of many of the weeds unearthed from assemblages on the Chengdu Plain was poor and did not allow me to make

identifications beyond the family level. This made it difficult to ascertain with certainty if weeds belonged to a rice paddy or to a field of another dryland crop.

As was shown by the analysis carried out in section 8.4 of this chapter, the number of weeds that could be confidently ascribed to a wetland environment were high at the site of Baodun (mostly because of the presence of *Fimbrystilis*), but their numbers were much lower in other periods of the site occupation. The reasons for this are unclear. It is possible that this may be due to crops being more fully processed immediately after the harvest, on some central location offsite. However, this may also simply reflect that more intensive weeding practices took place during these periods, leading to less weeds being present in the site. While studies of crop processing can provide useful information about past labor organization, it is necessary for them to meet the criteria described above in order to be carried out successfully. Further research on these issues in southwest China has the potential to yield exciting results about ancient labor organization, however a much better understanding of weed taxa identification criteria is needed to carry out this work.

Summary

The ample water resources and clement climate of the Chengdu Plain made it well adapted for the intensification of rice agriculture. However, several changes in agricultural strategies are visible throughout its occupation. The first is an apparent increase in the numbers of and diversification of dryland crops during the late Baodun. It is interesting to note that this corresponds to a known lessening intensity of the summer monsoon recorded in the Dongge stalagmite c. 1900 BC, that may also correspond to a decrease in temperature (Dykoski, et al.

2005). Around the same period of time, cooling events are also known from the Dunde Icecore (Thompson, et al. 1990) and pollen records at Erhai that demonstrate that a cooling event took place somewhere between 2500-2100 BC (Dearing, et al. 2008; Shen, et al. 2006; Yang, et al. 2005; Z. Zhang, et al. 2000). Further work is needed to determine the exact timing of this event and whether or not this could have caused an increased reliance on dryland crops in the Chengdu plain.

Compared to the surrounding highlands, agricultural strategies on the plain are characterized by a high degree of stability, indicating that its inhabitants founded a sustainable and reliable agricultural system based on rice and foxtail millet. The versatility of this dual cropping system allowed its inhabitants to adapt in the face of climate change, as was seen by the increase in dryland crops during the late Baodun, followed by a return to an emphasis on rice in the subsequent period.

This system was able to support the large population densities and high degree of social complexity achieved by the inhabitants of the plain. Urban centers, the presence of a class of ritual specialists and the presence of what must have been workshops to create the paraphernalia associated with these rituals meant that a good portion of the population were not involved in full time food production. An analysis of crop processing revealed that the final stages of crop processing were carried out on site, and that rice was stored on site in a hulled form and processed on a daily basis. I was not, however, able to detect any changes in crop processing strategies over time that could reflect changes in labor organization. It is likely that this could be due to the difficulty in identifying the weeds associated with paddy cultivation and relatively

small number of weeds concerned. Further work on identification criteria and larger, better preserved samples may help elucidate these patterns.

CHAPTER 9

CROP GLOBALIZATION AND INNOVATION: LATER HISTORICAL TRENDS IN THE SPREAD OF AGRICULTURE TO SOUTHWEST CHINA

Around the beginning of the 2nd millennium BC, crops originally domesticated in the Fertile Crescent begin to appear in East Asia. The introduction of these crops had a profound impact on both agricultural strategies and food traditions in China as a whole, and also on agricultural strategies in Southwest China. The patterns of uptake of these domesticates were highly variable across this area, and ecological conditions may have played an important role in these differences. On the Tibetan Plateau, the introduction of these domesticates played an important role in the development of a settled lifestyle. This chapter summarizes the evidence for the spread of western domesticates into East Asia and into surrounding regions. In a second step, I review the evidence for this spread into highland and lowland Southwest China, using data from sites in the Chengdu Plain, Western Sichuan, and Yunnan Province. Finally, I discuss the current evidence for the introduction of these crops to the Tibetan Plateau.

Jones et al. (2011) argue that the brevity of the growth cycle and ripening period of broomcorn millet, foxtail millet, buckwheat, wheat and barley may have played an important role in influencing the manner in which these crops spread across Eurasia. They argue that the length of the growing season dictated which crops were able to spread first. In particular, they argue that because of their short growing season, millets and buckwheat (during the 6th and 4th millennium BC) were the first domesticates to spread across Eurasia. They hold that only later (during the 3rd millennium BC) were ecologically more demanding crops such as wheat able to spread.

In reply to this article, Boivin et al. (2012) argue that there is no relationship between length of growing season and a crop's uptake. They further argue that early finds of broomcorn millet outside of China are rare and mostly postdate 2000 BC, and emphasize that buckwheat was not widely found outside China and most reliable finds are quite late (after 2500 BC).

Boivin et al. (2012) argue that the social processes underlying the uptake of these new crops are equally important and must be considered. They point out that, although the introduction of new crops can sometimes reflect a desire to increase agricultural stability and production, new plants were more commonly sought for ritual, medicinal and prestige purposes. They argue that the introduction of new species of crop could not have been solely due to a desire to increase production as there was often a delay of millennia between the introduction of crop into a new environment and its cultivation on a significant scale. They emphasize that new crops could have filled a variety of different functions including "cash crops," "spices/exotica," "risk buffering crops" and "staple foods" (Figure 9.1).

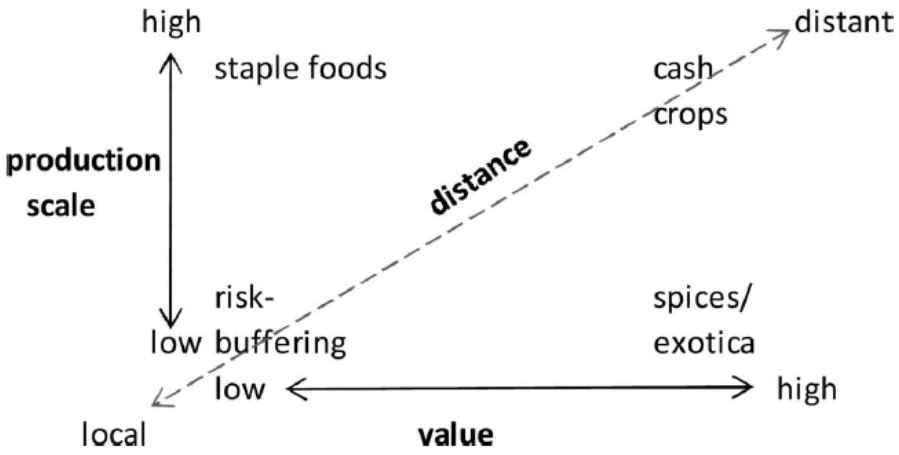

Figure 9.1. Modified after Boivin et al. (2012: Figure 3). Representation of the relationship between crop use categories and three interacting variables: the social value placed on a crop, the scale of production and the distance from which a crop is obtained by direct trade for consumption.

Based on data derived largely from the Central Plains, Boivin et al. (2012) argue that the minute quantities of wheat found there do not support the claim that this crop played any major caloric role upon its initial introduction to China. Instead, they argue that during the Bronze Age in China, wheat functioned as a spice or exotica, and did not form a major component of the diet. Between the Iron Age and the Han, wheat began to play a role as a risk buffering crop. Only after the Han and following the introduction of rotary querns allowing it to be turned into flour did wheat become a staple crop. In contrast, Boivin et al. (2012) argue that the wheat's uptake in North and Central India followed a different trajectory, and was quickly taken up by farmers due to different traditions of food preparation, namely familiarity with breads.

This chapter examines the different patterns of crop uptake and use, employing ecological niche modeling and an analysis of growing degree days. I demonstrate that ecological conditions did play a role in helping decide which crops were adopted by ancient agriculturalists in this area. However, unlike Jones et al. (2011), I argue that the number of growing degree days was more important than the length of the growing season. In addition, cultural values seem to have had an important impact on crop uptake patterns.

9.1 Spread of western domesticates to East Asia

Evidence for the timing of the spread of western domesticates into East Asia is becoming increasingly well documented.

Wheat (*Triticum* spp.) and barley (*Hordeum vulgare*) were domesticated in Southwest Asia by c. 8000 cal. BC and from there moved into western and central Europe (Jones, et al. 2011; Zohary and Hopf 2000). Western domesticates appear to have arrived in China sometime around the beginning of the second millennium BC. In southeastern Gansu province, the earliest evidence for southwest Asian domesticates probably comes from the site of Xishanping, where wheat, barley and other domesticates were found in a context that is thought to date between 2700-2350 BC (Li, et al. 2007). Another potential early find comes far to the east from the site of Liangchenzhan in Shandong province, where bread wheat was found in association with Longshan period pottery (2600-1800 BC) (Crawford, et al. 2005). Unfortunately, no direct dates were carried out on grains so it is difficult to assess the validity of these finds. Securely dated evidence for wheat and barley comes from the site of Donghuishan in the Hexi corridor of Gansu, c. 1700 BC, although one grain of wheat from this site was directly dates to the 3rd millennium

BC (Flad, Li Shuicheng, et al. 2010). Wheat became established in the Central Plains c. 1600 BC and spread to the Korean peninsula by 1000 BC (Crawford and Lee 2003; Lee, et al. 2007).

Areas situated at the margins of China contain important evidence for the spread of western domesticates into East Asia. In Central Asia, the earliest evidence comes from Jeitun (Harris 2010), a Neolithic (c. 6000 B.C.) village in western Turkmenistan. The agricultural assemblage at Jeitun consists of glume wheats and hulled barley, a combination that does not appear in later Central Asian contexts. The river valleys and alluvial fans of the ecotone between the Kopet Dag Mountains and the Kara Kum Desert fostered many sedentary villages from the fourth through the first millennia B.C. The most northeasterly of these villages, and one of the earliest and largest yet identified, is Sarazm. Sarazm (c. 3500-2000 B.C.) is interpreted as an outpost trading and mining village. People at Sarazm engaged in an agropastoral economy, with a human foraging component. Crops cultivated at the site included free-threshing wheat and both naked and hulled barley (Spengler and Willcox in review).

By the mid-third millennium BC, Namazga Culture sites along the Kopet Dag foothills, such as Gonur Depe and Djarkutan, have agricultural assemblages, including free-threshing wheat, naked barley, peas, lentils, chickpeas (*Cicer* sp.), possible grass peas (*Lathyrus* sp.), and grapes (*Vitis vinifera*) (Miller 1999; Moore, et al. 1994). Evidence from Begash shows that free-threshing wheat spread north into the Dzhungar Mountains of eastern Kazakhstan by c. 2200 cal. BC (Frachetti, et al. 2010). In the same context at Begash, broomcorn millet was recovered; Frachetti et al.(2010) suggest a reciprocal movement of broomcorn millet into Central Asia from China and wheat in reverse. Broomcorn millet does not appear in southern Central Asia until the

early second millennium BC at Shortughai, Afghanistan (Willcox 1991). Despite its presence at Shortughai, broomcorn millet is not present at other second millennium BC village sites in southern Central Asia (Miller 1999).

To the south, it is also important to consider evidence from sites surrounding or in proximity to the far western corners of the Tibetan plateau. In the Kashmir region of northern South Asia, data from the sites of Burzahom, Gufkral and Semthan in territory claimed by India show that between c. 2800 and 2300 BC, a suite of western domesticates (wheat, barley, pea, lentil) were present (Knörzer 2000; Lone, et al. 1993; Sharma 2000). In the Swat region of Pakistan, data from the sites of Ghalegay, Bir-kot-ghw and Loebanr show that a compact form of wheat was present as early as 2400 BC. Starting at 1900 BC a suite of other western domesticates appear in the record including barley, pea, lentil, flax and domesticated grape (Costantini 1987). Paleoethnobotanical analyses carried out at the sites of Mebrak and Phudzeling (1000 cal BC to 100 cal AD) in the Jhong valley in Upper Mustang, Nepal, show that during the first millennium BC a wide variety of Near Eastern domesticates were present in these areas. These include barley (*Hordeum vulgare*), buckwheat (*Fagopyrum cf. esculentum* and *F. tataricum*) and flax (*Linum usitatissimum*) (Knörzer 2000). At around 400 BC, bread wheat (*Triticum aestivum*), broomcorn millet, pea (*Pisum sativum*), as well as lentil (*Lens culinaris*) and hemp (*Cannabis sativa*) appear in the record. In Bhutan, no archaeobotanical analyses have been carried out, although, according to Meyer et. al (2009) cereal pollen increases sharply in the record at c. 2200 cal BC. Meyer interprets this increase in cereal pollen as being associated with the beginnings of cereal cultivation in this area. More evidence is needed to test this hypothesis.

During the 1980s botanical surveys on the Tibetan plateau found populations of wild barley (*Hordeum spontaneum*) that were similar to the progenitor of West Asian domestic barley present on the Tibetan plateau (Molina-Cano, et al. 2002). Genetic studies of these populations of wild and domesticated barley population structure have suggested that the Tibetan plateau could be considered a separate center for barley domestication (Ma, et al. 1987; Xu 1982). However, a recent article points out that that the close relationship seen between modern varieties of Chinese hull-less and six-row barleys could have been due to gene flow between populations of wild Tibetan barley that grow alongside domestic crops as weeds (Dai, et al. 2012). Until archaeological evidence to support one or the other (or both) of these hypotheses becomes available, it will be difficult to choose between these possibilities.

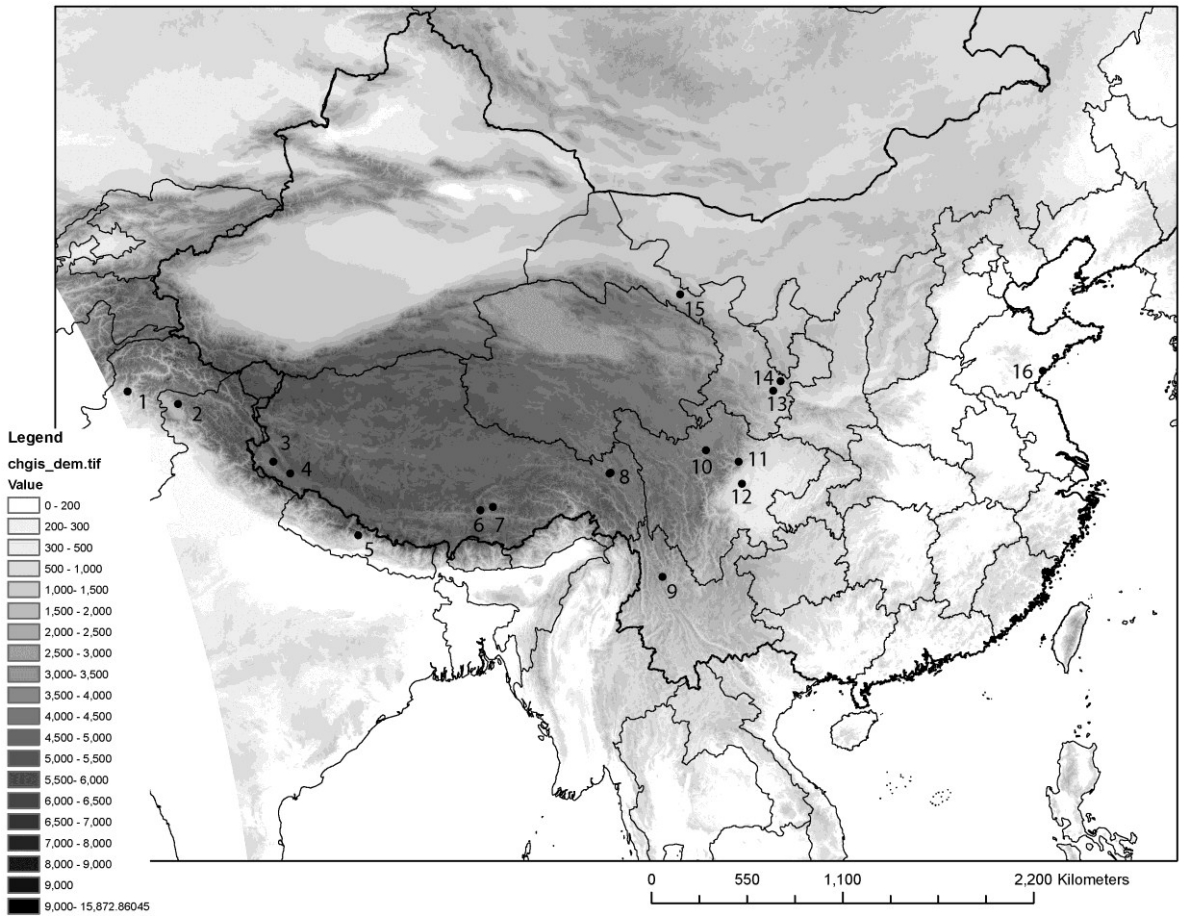

Figure 9.2 Sites discussed in the text 1.) Ghalegay, 2.) Burzahom, 3.) Dingdun, 4.) Kyung-Lung Silver Castle, 5.) Kohla, 6.) Changguogou, 7.) Lhasa, 8.) Changdu Karuo, 9) Haimenkou, 10) Benjiachi and Yanerlong, 11.) Yingpanshan, 12) Jinsha, 13) Xishanping, 14) Dadiwan, 15) Donghuishan, 16) Liangchenzhen

9.2. Wheat and Barley in Western Sichuan

To date, archaeobotanical analysis in Western Sichuan has focused primarily on remains dating to the earliest movement of agriculture into the area and as a result more is known about the earlier movement of millet agriculture into this region, than about the later movement of western

domesticates. Excavations by the Sichuan Provincial Institute of Archaeology and by Kyushu University in Japan at the sites of Benjiachi and Yan'erlong have revealed that the inhabitants were reliant on wheat and barley. Radiocarbon dating on the site of Yan'erlong has led the authors to divide the occupation of the site into three periods: phase 1 that dates roughly to 1500 BC, a second phase characterized by cist tomb burials that dates to 1500 BC-800 BC based on direct radiocarbon dating of human bones, and a third phase dating to the 6th to 7th century BC (Cheng 2011; Sichuan Sheng Wenwu Kaogu Yanjiusuo, et al. 2012). Flotation samples from the Yan'erlong site revealed that the inhabitants had an agricultural system based on barley, whereas both barley and wheat were found in flotation samples from the site of Benjiachi. It is, however, unclear at this point which phase these samples belonged to. Given the close cultural ties that sites of the cist tomb culture share with the Qijia-Siwa culture, namely in terms of the *shuang'erguan* pottery, (who already cultivated wheat and barley) it is not surprising that remains of both should be found in these contexts (Flad, Li Shuicheng, et al. 2010). Full publication of this material will help clarify these patterns.

9.3 Western domesticates on the Sichuan Basin

The analysis of samples from the Chengdu Plain reveals that during the Bronze Age, small amounts of western domesticates were used by the inhabitants of this area. During the Shi'erqiao period (c.1200-800 BC), both wheat and barley appear in the record, albeit in very small quantities. Only five caryopses of each were unearthed despite the high volume of soil floated and the high seed density. One poorly preserved caryopses of barley was found at Qibazu, three were unearthed at Qingchengjian, and one at the site of Yantangcun in Xindu county in layers

dating to the early Shi'erqiao. Three caryopses of wheat were unearthed at the site of Yongfucun in Wenjiang in layers dating to the Early Shi'erqiao period and two were found in early Shi'erqiao layers at Yantangcun. Thus, despite the presence of wheat and barley in the mountainous peripheries of the Sichuan Basin almost 200 years prior to its introduction to the Chengdu Plain, these crops do not appear to have been readily used and form a very tiny percentage of the overall crop assemblage. Their low numbers further suggest that these crops may not have been grown locally and that they could have been exchanged with individuals inhabiting other ecological niches, possibly the highlands surrounding the plain.

Table 9.1 Cereal proportions on the Chengdu Plain.

	Guiyuanqiao	Baodun Early	Baodun Late	Sanxingdui	Shi'erqiao
Rice whole +frag / total cereal	0	0.89	0.57	0.87	0.76
Foxtail Millet/ total cereal	0.05	0.10	0.30	0.14	0.23
Broomcorn Millet (ct)/total cereal	0.94	0.001	0.12	0.008	0.007
Barley (ct)/ total cereal	0	0	0	0	0.0004
Wheat (ct)/ total cereal	0	0	0	0	0.0004

9.4 Western domesticates in highland Yunnan: Haimenkou

The Haimenkou site contains important evidence for the spread of western domesticates into southwest China.

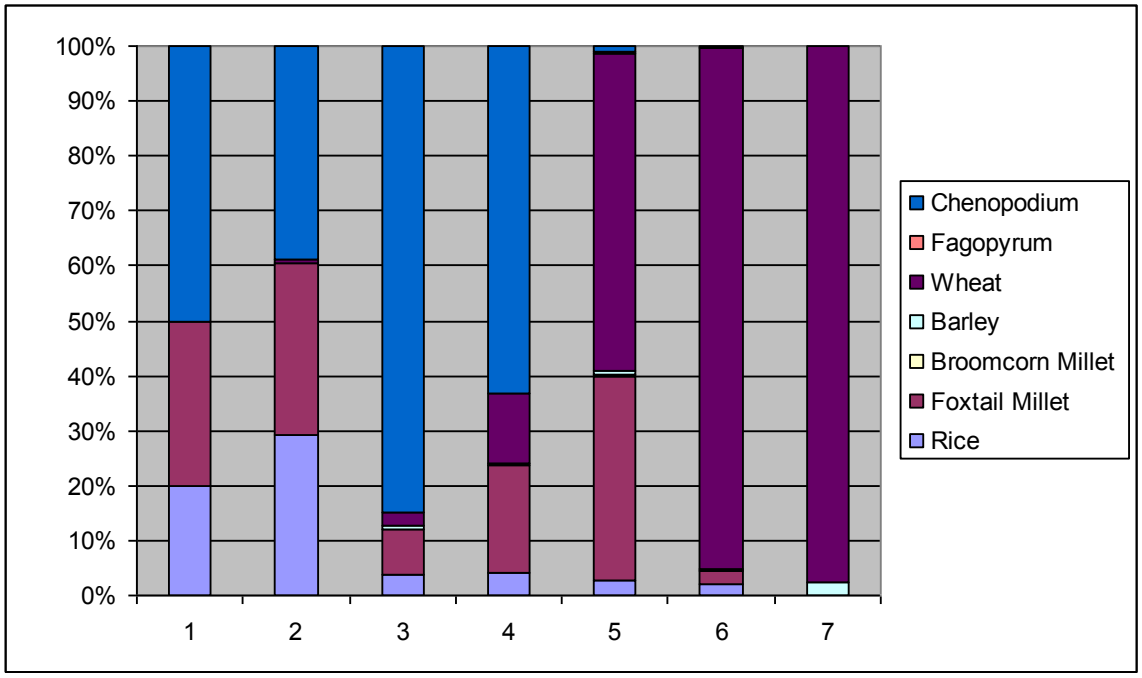

Figure 9.3 Archaeobotanical material unearthed from Haimenkou. 1) layers 9, 2)layer 8, 3) layer 7, 4) layer 6, 5) layer 5, 6) layer 4, 7) layer 3 After analysis carried out by Xue (2010).

The earliest layers of occupation at the site (10 and 9) only contain evidence for rice and millet agriculture. Tiny amounts of western domesticates appear in layer 8 (approximately 1600-1400 cal BC). According to Xue's (2010) analysis, in layers 8, wheat begins to appear in the samples, however it forms only 0.6% of the cultivated crop assemblage and is represented by only 5 specimens. As discussed in Chapter 7, starting at around 1400 BC, in layer 7, the proportion of rice in the assemblage decreases dramatically and wheat begins to slowly increase. Two caryopses of barley also appear in the layers dating to this period of time. Interestingly, the proportion of *Chenopodium* increases sharply (Figure 9.3). Layer 6 continues the tendencies of layer 7, and the proportion of rice continues to decline, while *Chenopodium* continues to increase. The proportion of wheat increases steadily in these samples. Major changes occur in level 5 and wheat begins to dominate the assemblage and now forms over half of all food crops. At the same

time, *Chenopodium* almost completely disappears and foxtail millet increases again in the assemblage. A few specimens of rice are still present in the layers dating to this period. In layers 3 and 4 of the site, this trend continues until wheat forms over 90 percent of the total crop assemblage.

Jin (2012) has argued that the movement of wheat to the Yunnan-Guizhou plateau may have taken place as the result of a migration of inhabitants of the Qijia culture (2400-1900) from Northern Gansu, following dramatic climate change. She argues that the occupation of the Haimenkou site dates to roughly 200 years after the abandonment of Qijia culture sites in the north and that its inhabitants may have migrated southward in search of more clement climates. Ceramics associated with this culture and known as *shuanger'guan* (flat bottomed double handled amphora) are found throughout highland southwest China and are distributed in the upper Minjiang, valley, Eastern Tibet, Northwestern Yunnan, Southwestern Sichuan, and areas to the west of the Dianchi lake and to the East of Lake Erhai. These ceramics were initially only known from burials that are associated with the cist tomb culture, where they are found in rock cut graves, cist graves, and brick and stone burials (Xie 2005). In Yunnan, these amphora are found in both earthern pit and cist tombs, and at Haimenkou they have been found throughout all sites and features post dating 1400 BC. The appearance of wheat and barley at Haimenkou, as well as at Benjiachi and Yan'erlong coincides with the presence of pottery vessels and bronze implements similar to those of the Qijia culture, suggesting that these people may have been instrumental in the movement of western domesticates into this area.

9.5 Movement of western domesticates onto the Tibetan Plateau

9.5.1 The early introduction of domesticates to the site of Changguogou:

Evidence from Changguogou in Gongga county, 50 km west of Lhasa in central southern Tibet, indicates that western domesticates had been moved onto the Tibetan plateau at least by the end of the second millennium or the beginning of the first millennium cal. BC (Fu 2001b). Two radiocarbon dates carried out on the site, gave dates that ranged from 1500-800 cal BC (Table 9.2 and Figure 9.4). The 1994 excavations at the site revealed a large ashpit (H2) that contained a deposit more than 1 meter thick of carbonized material (Fu 2001). A number of domesticates were found in handpicked samples from the excavations (Fu 2001; Fu, et al. 2000). These include what appears to be a free threshing variety of wheat (*Triticum sp.*) (based on a published image), naked barley (*Hordeum vulgare* var. *nudum*), foxtail millet, a single pea (*Pisum sativum*), rye (*Secale* sp.), and naked oat (*Avena nuda*). In addition, a well-preserved tuber that Fu et al. (2000) identify as drolma (*Potentilla anserine*) was recovered. According to written sources from the beginning of the century, roots of *Potentilla* were consumed in the area around Lhasa and are still consumed in the region today, particularly during the Tibetan New Year (Chandra-Das 1902; Rockhill 1894; Thargyal 2007). A seed coat of a pine nut (originally described in Fu (2000 and 2001:Fig. 2), as an unidentified specimen) was also found in the assemblage from Changguogou. The finds from Changguogou illustrate that a wide range of Southwest Asian domesticates, either locally grown or derived from trade, were moved onto the Tibetan plateau and may have been experimented with by early Tibetan farmers.

Table 9.2 Radiocarbon dates carried out at the site of Changguogou.

Site	Feature	Date	+-	Material
Changguogou	H2	2958	102	Wood charcoal
Changguogou	H2	2814	99	Animal Bone

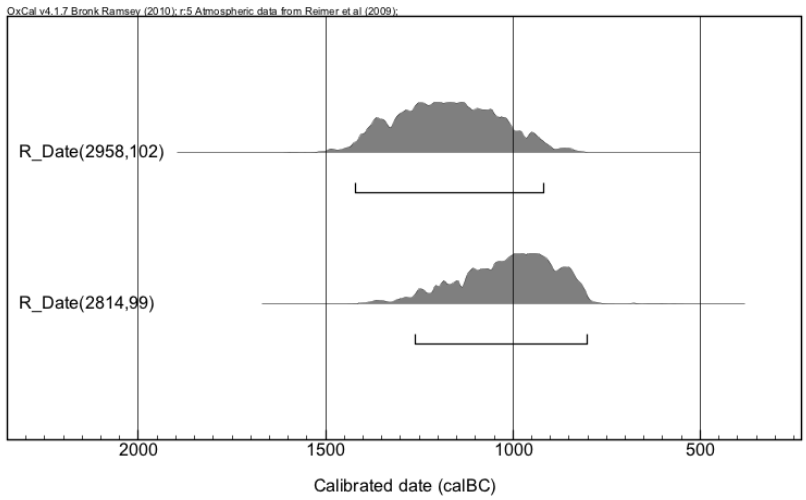

Figure 9.4 Calibrated radiocarbon dates from the site of Changguogou, showing the two-sigma probability intercepts with the calibration curve (from IntCal 2009). Dates are in order of uncalibrated radiocarbon determination.

9.5.2 Later evidence from Western Tibet

A gap of almost 1500 years exists between the site of Changguogou and later sites containing archaeobotanical evidence on the Tibetan plateau. Many have argued that during this time period (c 800 BC – AD 400) a transition toward a more mobile economic system depending on pastoralism took place in Central Asia (Khazanov 1984; Kuz'mina 2000; Wagner, et al. 2011). The model suggests that an economic system almost exclusively based on sheep, goat, and horse pastoralism quickly spread across Central Asia and brought with it a distinct cultural package, including horse breeding, advanced metallurgy, and animal-style decorations. Recent excavations at the cemetery site of Liushui (1108 – 893 BC) in the Kunlun Mountains of southern Xinjiang have shown that cultural and economic traits similar to those known from Central Asian sites were present in mountainous parts of western China by this time period

(Wagner, et al. 2011). Paleoethnobotanical studies in this region suggest that in addition to pastoralism, the regional economic system was at least partly based on agriculture (Chang, et al. 2002; Di Cosmo 1994).

a.) Kyung-lung Mesa

The site of Kyung-lung Mesa is believed to be the capital of the pre-Buddhist kingdom of Zhangzhung and thus holds an important place in Tibetan history (Aldenderfer and Moyes 2005; Li and Huo 2005)[7]. A collaborative survey of the site, located in far southwestern Tibet near the headwaters of the Sutlej River, was carried out in the summer of 2004 by a joint team from Sichuan University and the University of Arizona. The site is situated atop a large mesa, and remains of numerous buildings and refuse pits are visible on the surface. Stone mortars, grinding stones, and querns were also visible. I analyzed samples extracted from two different units: Structure 66 (SX223 and SX225) and from a residential structure in area B of the site (SX224). I sent archaeobotanical material unearthed from these units for direct dating at Peking University. The northern area of the site (Area B) was found to date to roughly cal. AD 220-334 and Structure 66 yielded a range of cal. AD 694-880 (Figure 9.5). These results indicate that the site was occupied over a relatively long period of time and are not surprisingly much later than dates previously obtained from the site on wood charcoal and bulk sediment (See Table 9.3).

[7] There is some controversy over the name "Silver Castle (or Palace)". To some, the term should be reserved for a Buddhist-era archaeological site approximately 2 km from the modern village of Kyung-lung on the Sutlej River, and which is some 15 km downstream from the site described in this manuscript. This site was visited by Giuseppe Tucci in the 1930s and is known by the Tibetan name Kyung-lung Ngulkhar. The putative capital of the Zhangzhung polity is sometimes labeled "Silver Castle" as well. We prefer to use the term Kyung-lung mesa" to describe this site, which also has the local Tibetan name of Kyung-lung Yulkhar.

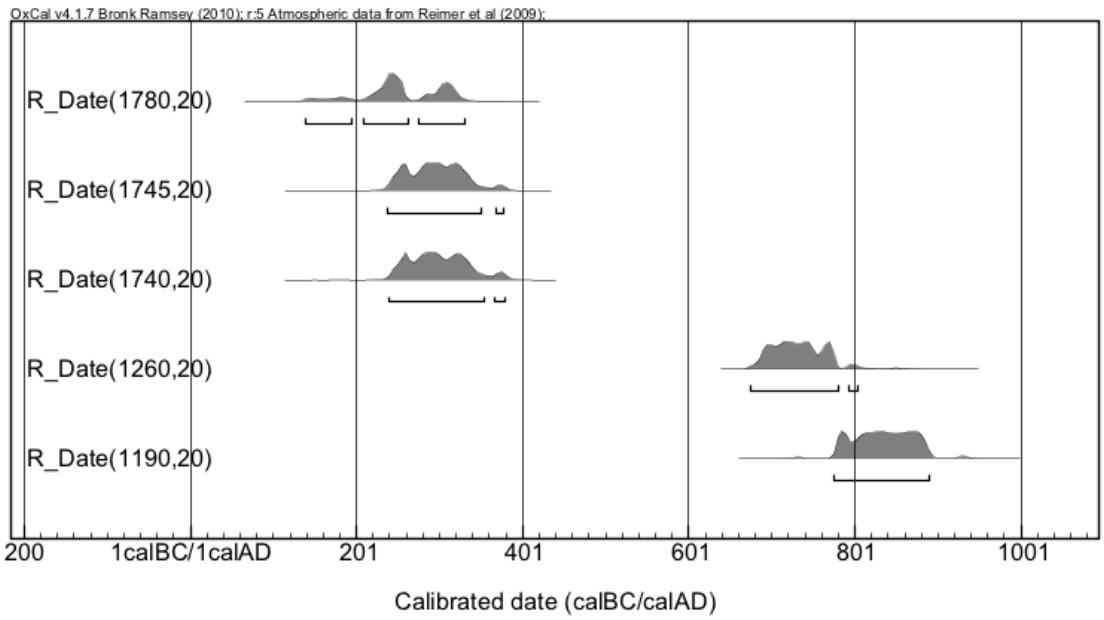

Figure 9.5 Calibrated radiocarbon dates from the site of Kyung-Lung Mesa, showing the two-sigma probability intercepts with the calibration curve (from IntCal 2009). Dates are in order of uncalibrated radiocarbon determination.

Table 9.3 Radiocarbon dates carried out at the site of Kyung-lung Mesa

Site	Feature	Lab No.	Date	+-	Material
Kyung Lung Silver Castle	KLB 区北端	BA111234	1780	20	Carbonized Matrix
Kyung Lung Silver Castle	KLB 区北端	BA111235	1745	20	*Hordeum* grain
Kyung Lung Silver Castle	KLB 区北端	BA111236	1740	20	Twig
Kyung Lung Silver Castle	Structure 66	BA111237	1260	20	Dung
Kyung Lung Silver Castle	Structure 66	BA111238	1190	20	*Hordeum* sp.
Kyung Lung Silver Castle	KL04-32	?	?		Wood charcoal
Kyung Lung Silver Castle	KL04-66	?	?		Wood charcoal

Table 9.3 Continued					
Kyung Lung Silver Castle	04KLB	?	1910	104	Wood charcoal
Kyung Lung Silver Castle	04KLA S66.2	?	2110	115	Wood charcoal
Kyung Lung Silver Castle	04 KLA S66.3	?	1810	109	Animal bone
Kyung Lung Silver Castle	04KLA W1	?	3230	160	Sediment
Kyung Lung Silver Castle	04KLA W2	?	3550	740	Animal bone
Kyung Lung Silver Castle	04 KLB N1	?	2460	100	Sediment
Kyung Lung Silver Castle	04 KLB N2	?	2890	153	Sediment
Kyung Lung Silver Castle	04 KLA S10.1	?	3280	143	Wood charcoal
Kyung Lung Silver Castle	04 KLA S32.1	?	3470	958	Sediment

The archaeobotanical sample from the northern area of Kyung-lung Mesa (Sample BA111234-36) contained large quantities of uncarbonized wood and other plant materials as well as a large number of fish, amphibian, and small animal bones. I identified one poorly preserved carbonized barley grain, a number of desiccated barley rachi, as well as a few palea and lemma of foxtail millet. In addition, I recognized one pine nut seed coat (*Pinus yunnanensis/tabulariformis*), *Fragaria/Potentilla* seeds and a variety of other wild herbaceous seeds (Appendix D).

The pine nut seed coat is small, measuring roughly 4mm long and 2mm wide. The majority of species of pine consumed today (*P. armundii*) produce nuts that are larger than those found in our sample (Personal observation: Robert Spengler 2011). There are, however, a few species of pine that produce edible nuts, grow at high altitude and produce seeds of these dimensions. These include *P. yunnanensis* and *P. tabuliformis* (Wu, et al. 1999). The pine seed fragment I recovered from the assemblage at Kyung-lung is morphologically most closely related to those

two varieties of pine. They are both species endemic to the region and have historically been used as a food source by people in Yunnan and southern Tibet (Hu 2005; Simoons 1991). Pine nuts have also been discovered at Yangshao period sites in northern China (Chang 1986:112; Ho 1975:87; Simoons 1991) and may have complemented the diet of pastoralists in the high Himalaya. Many historic sources concerned with the Central Eurasian Mountains have discussed the importance of foraging as a component of a multi-resource pastoral system (Vainshtein 1980). In addition, desiccated pine bark fragments that correspond closely to those of modern species of *P. yunnanensis* and *P. tabuliformis* were recovered in the flotation samples from this part of the site indicating that these trees may have been used in other ways by the inhabitants.

Due to the find of an anthropomorphic statuette it is believed that Structure 66 at Kyung-lung Mesa may have served some kind of ritual purpose. Flotation samples were taken from the second stratigraphic layer of a small scale excavation unit inside this structure, which produced large numbers of animal bones and carbonized material. The samples from Structure 66 yielded carbonized caryopses of barley, free-threshing wheat as well as possible wild buckwheat nutlets (*Fagopyrum* sp.) (See Appendix D for figures of all these specimens). Morphologically, the barley grains appear to be from a six-rowed hulled form, but due to the degradation of the surface of a significant number of the (admittedly few) specimens, it is possible that many of them could be from a naked form. Two fragmentary caryopses of a compact form of wheat (*Triticum aestivum/turgidum*) were also found. Evidence from later sites in the same area suggests that barley appears to have formed a major component of the diet during the 1st millennium AD in this region (Fu 2008; Weber 2008)

In addition, nutlets of a small seeded (3mm diameter) species of buckwheat (*Fagopyrum* sp.) were found. We differentiated *Fagopyrum* from other similar members of the Polygonaceae family based on the following criteria: In *Polygonum* and *Rumex* the embryo is usually located axially or marginally, whereas in *Fagopyrum* the embryo is located at the center of the seed along side the two cotyledons that are folded inside it (Isley 1947:335; Kreft and Kreft 2000). Despite the fact that our specimens all lacked their fruit coat, no evidence of an axially located embryo was visible. A number of smaller nutlets that were too poorly preserved to be either called *Fagopyrum* or *Polygonum* were grouped together in a *Fagopyrum*/ *Polygonum* category. Ten different species of *Fagopyrum* are native to southwestern China and the Himalaya (Li and Hong 2003). The small size of the *Fagopyrum* nutlet found at Kyung Lung makes it likely that it is a wild species that grew in the area. Relatively little is known about buckwheat domestication, although it is generally accepted that it took place somewhere in southwest China or the Himalaya, which is supported by the distribution of wild members of the genus (Ohnishi 1998). The ability of buckwheat to grow on sandy and poor quality soils and the relatively short number of growing degree days required by this crop mean that it is well adapted to the upland environments that characterize the Himalaya (Edwardson 1995) (see discussion in chapter 5). Given the review of buckwheat discussed here, it does not appear that this crop was one of the first domesticates to move from Asia to Europe.

The earliest evidence for buckwheat comes from pollen cores from sites in Eastern Europe dating to roughly the 5th millennium BC, although it is likely that much of this pollen comes from one of its weedy relatives (Janik 2002). In Japan, a single achene has been found in Jomon deposits dating to the 5th millennium BC (Crawford 1983), however these were later found to be intrusive

(G. Crawford: Personal Communcation). Later finds of buckwheat are more reliable: the sites of Kohla in highland Nepal have yielded domesticated buckwheat achenes dating to the 1st millennium AD (Asouti and Fuller 2009). In Yunnan province, achenes of a small seeded species of buckwheat were found at the site of Haimekou in layers dating to c. 1400-800 cal. BC (Xue 2010). Although buckwheat appears to have been cultivated in the southern Himalaya well before occupation at Kyung-Lung Mesa, it is not clear if the small, likely wild seeds found at the site were brought there for human consuption (either foraging or low-investment cultivation). It is equally plausible that the seeds entered the assemblage via dung burning or seed rain.

From these samples, we were able to conclude that dietary pursuits at the site included a wide range of resources derived from farming (and possibly trade with farmers occupying areas of lower altitude), foraging, fishing and pastoralism. Our samples contained large amounts of carbonized sheep or goat dung (likely indicating penning) and it is important to consider dung burning as a source for many of the seeds found at the site. These dung remains are, however, mixed with midden deposits that contain not only botanical refuse, but also bones from small fish (less than six inches in length) and possibly amphibians, which were likely caught in or near mountain streams near the site (Appendix C). The presence of wheat and barley grains (and rachi) in contexts at Kyung-lung Mesa that also contain sheep or goat dung seems to suggest that some form of mixed agropastoral system was present on the plateau by the second or third century A.D. The switch from millet-based agriculture to agriculture based on Near Eastern domesticates on the Plateau may further support Wagner et al.'s (2011) argument that a steppe-style economy moved into western China by c. 800 cal. BC.

9.6 Ecological Niche Modeling and the Spread of Western Domesticates

The pattern of uptake of western domesticates in Southwest China show a number of different trajectories. I argue here that the ecological niches into which these crops were moved as well as their phenology played an important role in their spread. However, unlike the suggestions of Jones et al. (2011), I argue that the length of the growing season itself does not appear to have been an important factor.

In the Chengdu Plain, the adoption of western domesticates seems to have followed a similar trajectory to that observed in the Central Plains. The minute quantities of wheat and barley discovered in sites of the Shi'erqiao period mean that these crops may have functioned as spices or exotica, and it is highly possible that they were not even grown on the plain itself.

In highland southwest China, the introduction of western domesticates appears to have followed a very different trajectory. Although wheat is known at Haimenkou shortly after the beginning of the site's occupation, this crop is relatively rapidly taken up by the inhabitants. Following its introduction around 1500 BC, this crop rapidly overtakes rice in importance and becomes equal in proportion to foxtail millet (c.1200-1100 BC). After the site's abandonment for 300-400 years, occupants return with an agricultural system that is almost entirely based on wheat and foxtail millet with tiny proportions of rice (which at this point in time may have taken on the role of being a highly valued but difficult to grow crop for the reasons discussed in chapter 7). In layers 3 and 4, wheat completely overwhelms the assemblage becoming a staple food. Here it thus seems that wheat, which had originally been introduced as exotica, quickly became a risk buffering food, which served to safe-guard against the high risk associated with practicing rice agriculture in this highland environment. The risky environment appears to have precipitated the

rapid uptake of new and foreign domesticates. Compared to central China, the uptake of western domesticates at Haimenkou appears to have been relatively rapid as it takes only 300 years for them to become a important staple crops. After an additional 600 years, these crops overwhelm the assemblage. The transition thus occurs much faster than that described by Boivin et al. (2012) for Northern China. Although systematic collection of archeobotanical data is necessary to test this hypothesis, already at the current state of research it seems likely that a similar situation prevailed on the Tibetan Plateau. Populations on the Tibetan Plateau appeared to have favored the use of western domesticates soon after their introduction. Unfortunately no information was given on the relative quantities of millets and western domesticates from early sites like Changguogou, and as a result it is difficult to evaluate their importance in the diet. Evidence from Kyung-lung shows that during historical times, the cultivation of naked barley and buckwheat was favored over that of broomcorn and foxtail millets. The reasons for this are interesting to consider, and different explanations have been suggested by different authors.

Jones et al. (2011) argue that broomcorn and foxtail millets reach maturity in a shorter number of days than western domesticates such as wheat and barley. They hold that because of this shorter growing season, millets were some of the first domesticates to be moved throughout Eurasia as part of a risk management strategies in landscapes that were constrained by short growing seasons. Given the short growing season on the plateau, at a first glance it would seem that millets should have been favored by ancient farmers. However, the accumulated measure of heat (expressed in growing degree days) required by broomcorn and foxtail millets is higher than it is for the western domesticates since the millets have little to no tolerance for frost and their growth is stifled by cooler temperatures (see discussion in chapter 6). Both wheat and barley are able to

withstand frosts, and many varieties require cool temperatures to achieve maturity (Table 5.6). In particular, barley's short growing season of 60-100 days and high tolerance for low temperatures makes it well suited for growing on the plateau. For these reasons, barley was successfully introduced to a number of highland environments including colonial sites in the Andes (Jamieson and Sayre 2010). In addition, the possibility of gene flow between local populations of altitude-adapted Tibetan wild barley and introduced domesticates remains a fascinating possibility and may have allowed early Tibetan farmers to develop varieties that were well adapted to local climatic conditions.

Although we were only able to acquire climate data for one point on the Tibetan plateau itself, the analysis of growing degree days we carried out in Southwest China revealed that broomcorn millet was less adapted to cooler high altitude environments than foxtail millet. An analysis of the same regional data for wheat and barley shows that these crops fared better in these environments than both of the millets.

Wheat can occupy a range of different niches according to what variety is being grown. In China today, winter varieties of wheat are planted between mid September to October and are harvested from mid May until June. Winter varieties of wheat are require a period of dormancy, and begin growth in the early spring, once a 5°C threshold is reached (FAO 2012). In most areas of China, this is generally achieved around mid to late March. Spring wheat on the other hand is planted from mid-March through April and is harvested mid July through August. Because of the large overlap in dates it is generally not possible to grow both.

As a result, winter varieties of wheat tend to be grown in areas with warmer climates, and today Shandong and Henan are the major producers, with each province producing over 20 % of the nations winter wheat supply. Today, Heilongjiang and Inner Mongolia are the largest producers of spring wheat, producing 26% and 24% of the nation's spring wheat supply respectively (USDA 2006). Today winter wheats are not grown in highland Southwest China and are grown only in low lying areas such as the Chengdu Plain. Given the current distribution of these crops in China, it is likely that spring wheats were grown in upland western Sichuan, Yunnan and on the Tibetan plateau. Spring and winter wheat cannot be distinguished on a morphological basis and as a result we need to use ecological niche modeling to infer their use

Spring varieties of wheat require between 1800-2000 growing days, compared to winter varieties of wheat, which have a longer growing season and require between 1907-2100 GDD.

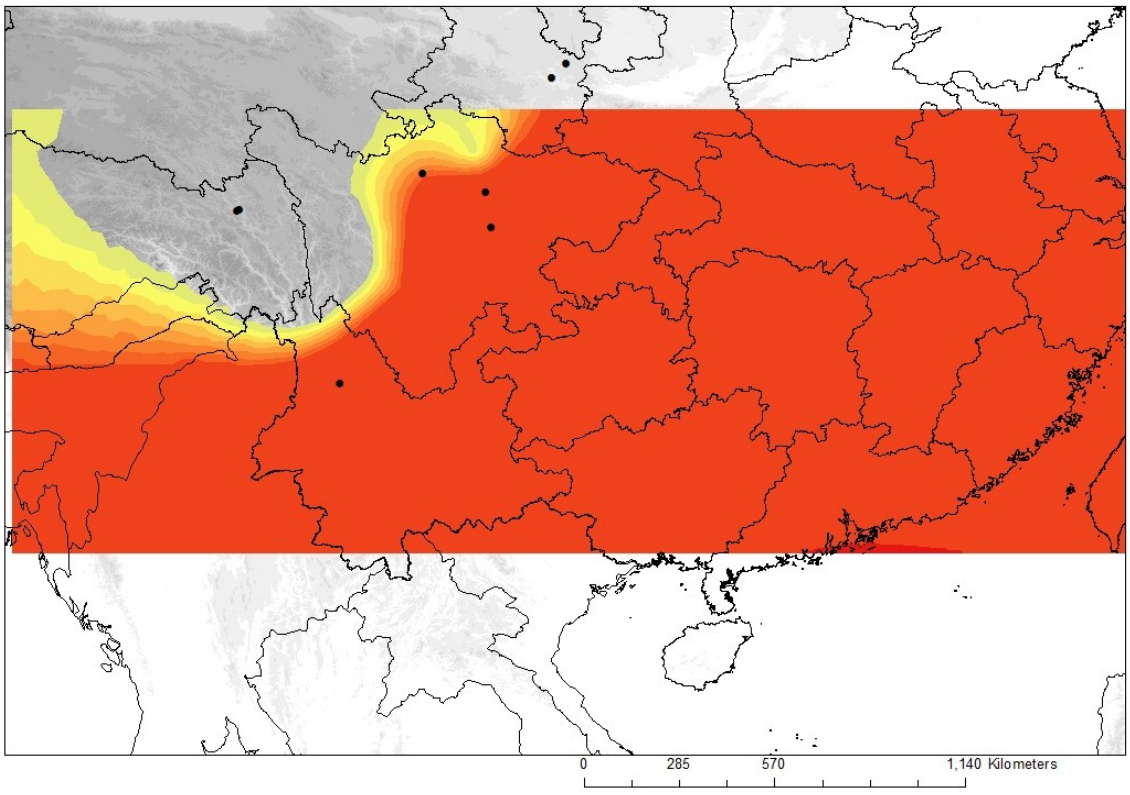

Figure 9.6 The potential distribution of spring varieties of wheat (regular). Map created on a 5.5 °C base. Spring wheat is reported as requiring between 1800-2000 GDD.

The map of the potential distribution of spring wheat shows that this variety of wheat could occupy a wide range of areas in highland western Sichuan, much of Northern Yunnan (Figure 9.6). For instance, the sites of Haimenkou, Benjiachi and Yan'erlong were all within the range where spring varieties of wheat could be grown. Spring wheat could also be grown in the area surrounding Lhasa. Unfortunately, we were not able to acquire weather data from the Eastern Tibet and as a result it is difficult to know how these crops may have performed here.

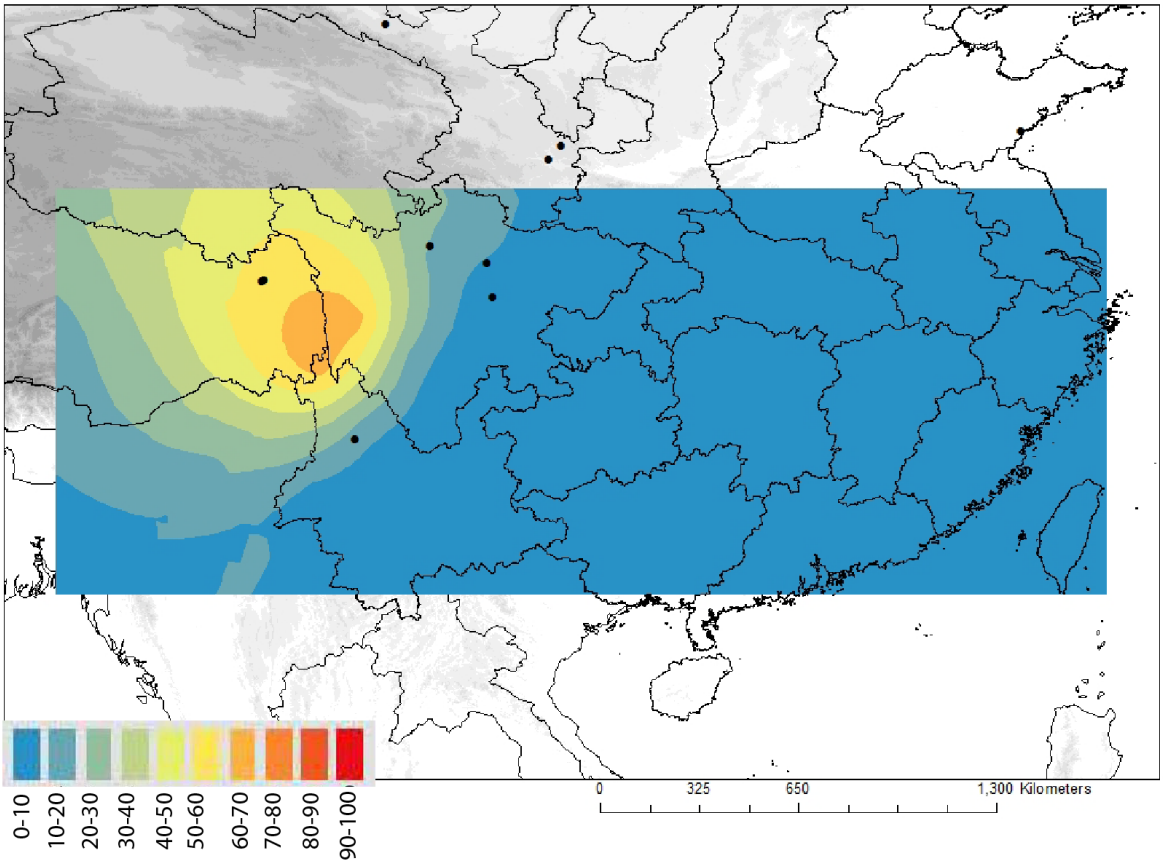

Figure 9.7 Risk map for Spring Wheat. Data processed using a 5.5 °C lower threshold and a 30°C upper threshold. Numbers represent the total percentage of years where failure occurred.

An analysis of risk revealed that in an area running from Songpan through Lhasa, Spring wheat could be grown with only 6-17% of failure, and the area of no failure growth extended from throughout the entire area of Eastern China up to the Chengdu Plain, and much of the Yunnan Guizhou plateau including Chuxiong and Kunming (Figure 9.7).

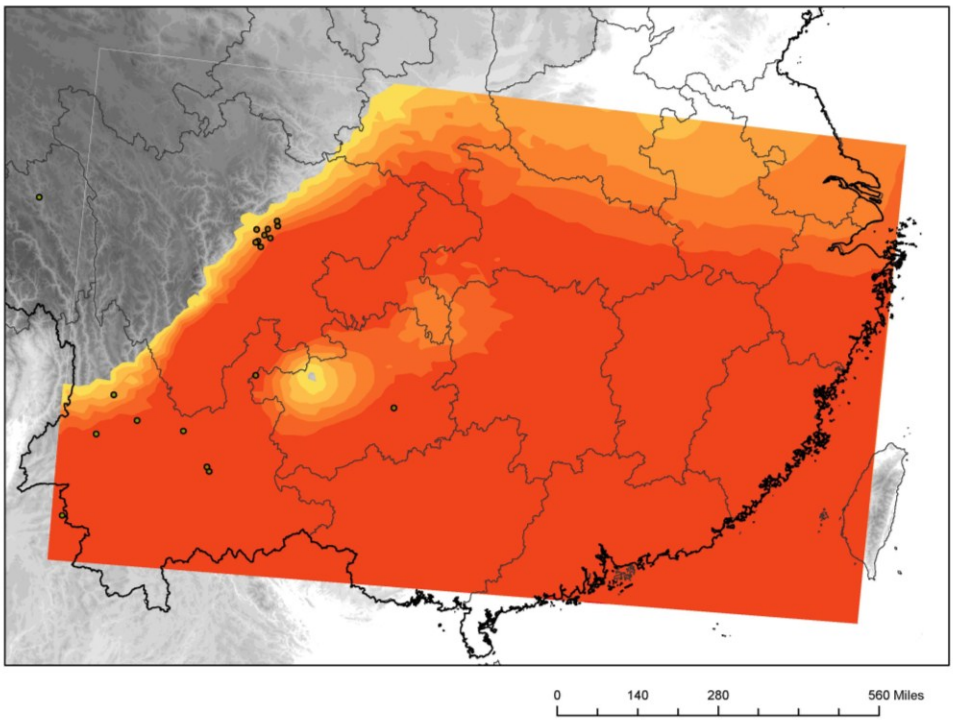

Figure 9.8 The potential distribution of winter varieties of wheat. Map created on a 5.5 °C base. Winter varieties of wheat require between 1900-2300 GDD.

Winter varieties of wheat can be grown in a similar area to spring varieties, however, they are able to cover less land in highland Sichuan and across the Tibetan plateau and northern Yunnan (Figure 9.8). In particular, the site of Haimenkou is situated at the margins of where winter varieties of wheat can grow today. An analysis of the risk for winter wheat shows that it has a probability of failure of 11-17% in upland western Sichuan and northern Yunnan. The site of Haimenkou is situated on the margin of this risky zone (Figure 9.9). This is interesting given that winter varieties of wheat are grown at the site today. Meadow (personal communication 2012) has observed that a wide variety of crops are grown around the site today in small fields, perhaps as a risk buffering strategy for this region.

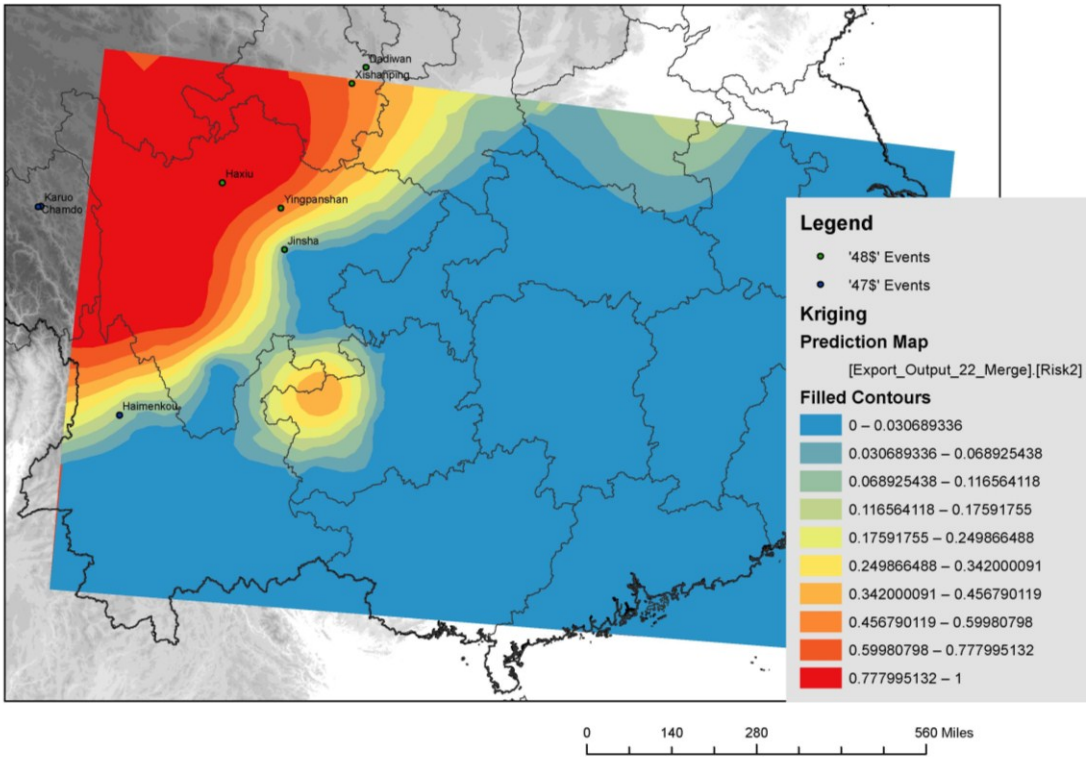

Figure 9.9 Risk map of Winter Wheat. Data processed using a 5.5°C lower threshold and a 30°C upper threshold. Numbers represent the total percentage of years where failure occurred.

Barley also has both winter and spring varieties. Like winter wheat, winter varieties of barley are sown in autumn and grow during the winter. It requires a sufficient amount of cold stimulus and following this stimulus flowers in the spring once the days grow longer. Spring barley is sown in the spring, does not require a cold stimulus, and begins to flower when the days get longer. Recent work on an early flowering variety of spring barley adapted to northern Europe has revealed that these varieties contain a mutation that damages their internal clock (EAM8), which they demonstrated through a comparison with the model plant *Arabidopsis*. The EAM8 mutation

causes the plant's internal clock to believe that the days are longer than they are. As a consequence, this variety of barley flowers much earlier than other spring barley varieties (Faure, et al. 2012).

Wild varieties of barley (*Hordeum vulgare* ssp. *spontaneum*) are all found to be of the winter variety aside from those that are believed to have gene introgression from spring varieties of barley (Takahashi, et al. 1968; Takahashi, et al. 1963). It is thus believed that the earliest kind of barley domesticated in the Near East must have been of a winter variety that was adapted to areas with relatively warm winters that could sustain plant growth (von Bothmer, et al. 2003). It is possible that the same may have been true for wheat. A mutation in the *sgh2* locus resulted in spring barley of *Sgh1Sgh2sgh3* type. However this mutation appears to have taken place multiple times throughout history (Pourkheirandish and Komatsuda 2007; Takahashi, et al. 1968; Takahashi, et al. 1963; von Bothmer, et al. 2003). It is argued that one of the pre-requisites for the expansion of barley (and of wheat), particularly into the northern latitudes of Europe, was the development of a spring phenotype (H. Jones, et al. 2011; Lister, et al. 2009; von Bothmer, et al. 2003). In high latitudes and areas with high altitude, spring barley is sown to avoid damage from cold winters, and today these are the varieties of barley grown throughout highland China. These spring and naked varieties of barley are grown in the Qinghai-Tibetan plateau, Northern Gansu, Aba and Ganzi districts in Sichuan and the Diqing district in Yunnan (He and Bonjean 2010). Spring barley is also grown in Heilongjiang, Jilin, Inner Mongolia, Hebei, Beijing and Shanxi through to Xinjiang (He and Bonjean 2010). Today, small amounts of winter varieties of barley are also grown in areas of milder winter temperatures in China including the Sichuan Basin, the Middle and Lower Yangzi, Shandong, northern Jiangsu and Anhui, southern Hebei, Henan, central Shaanxi, south Shanxi, and parts of Gansu. Winter barley is also grown in Guizhou,

Yunnan, Sichuan and Hunan at altitudes between 1000-2000 m. The measure of the number of growing degree days we were able to acquire for modern non-hybrid varieties of barley was somewhat higher than for that of wheat, and as a result the map of growing degree days associated with barley shows that it covered a smaller area than that of wheat (Figure 9.10).

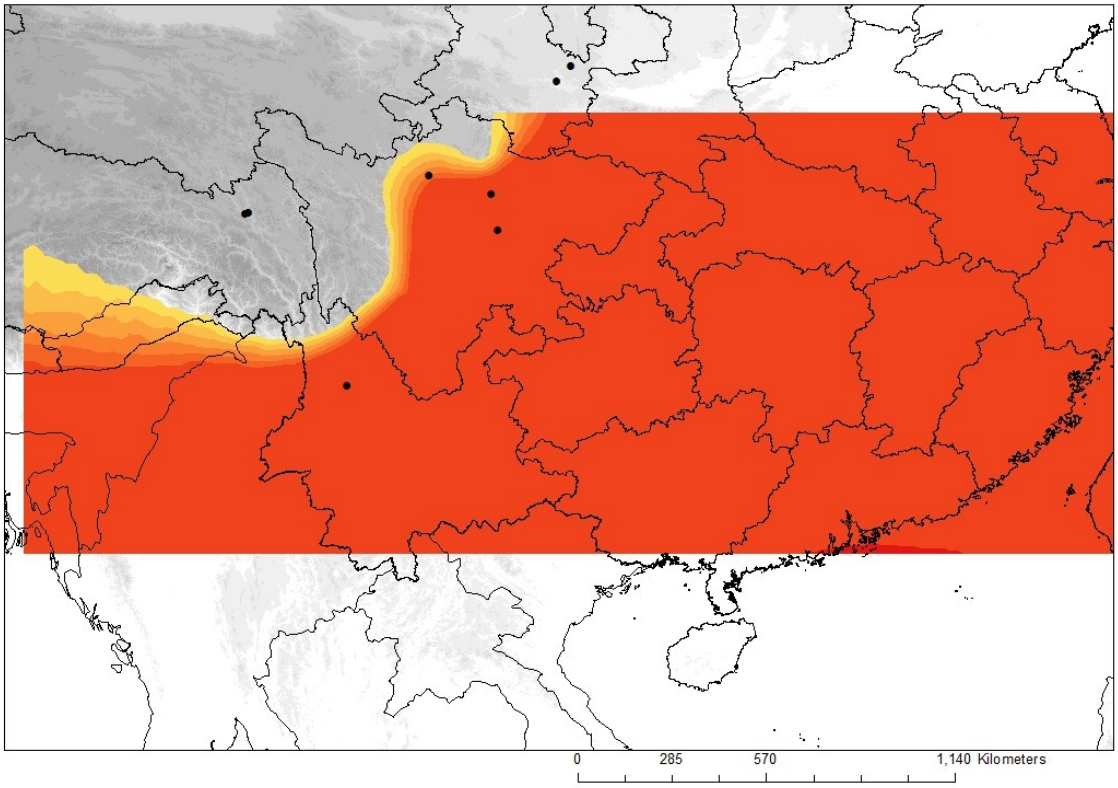

Figure 9.10 The potential distribution of spring varieties of Barley. Map created on a 5.5° C base. Barley is reported as requiring between 2084-2227 GDD.

Compared to the map of wheat risk, the map of risk associated with barley shows that a higher degree of risk is associated with practicing regular barley agriculture across southwest China. While for wheat a 6-17% chance of failure existed at Lhasa, for barley this risk factor was 15-23%. In addition, the area around Deqin and Litang presented a 63-74% chance of failure for barley, whereas for wheat this ranged between 57-73 % (Figure 9.11).

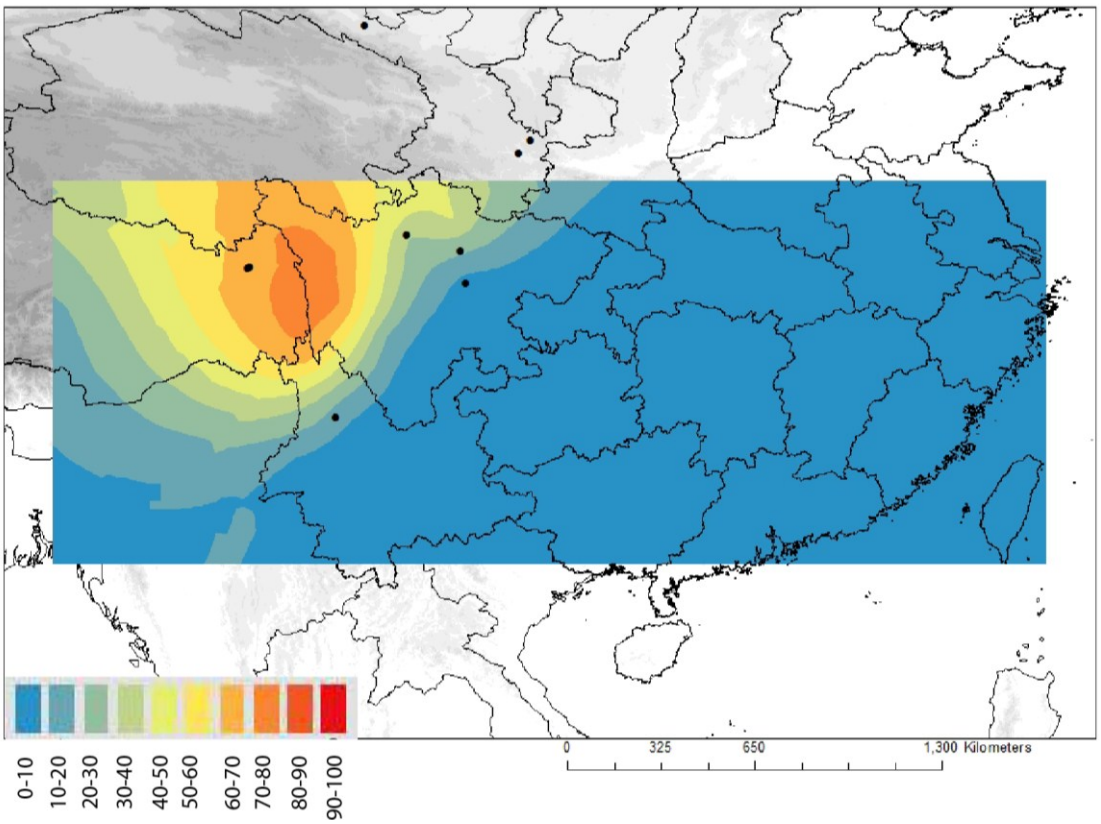

Figure 9.11 Map of the risk associated with cultivating barley in southwest China.

When thinking about barley and wheat phenology, it is also important to consider potential differences between modern cultivars and traditional landraces. However, to date no studies have been carried out on the number of growing degree days required for the landraces of these crops grown in China, and we can only use these numbers as an estimate. For instance, although no estimates of GDD are given, some barley landraces such as Chaguolan in Tibet have been said to be able to be planted at altitudes of up to 4200 m with a growing season of only 80 days (He and Bonjean 2010). Unfortunately there was no experimental data available on the growing degree days for these varieties. Future experimental work will help us determine how much variability there is in landraces grown in this area. In addition, the possibility of gene transfer from local

varieties of wild barley may have made introduced varieties even more adapted to the harsher conditions of the Tibetan Plateau. It is, however, highly likely that the as barley moved onto the Tibetan plateau, gene exchange with local wild varieties led to an increase in its ability to tolerate cold temperatures and in reality it was able to occupier a wider range of territory than that represented here.

The phenology of wheat may have played an important role in its success at the site of Haimenkou and throughout Southwest China. Both wheat and barley require slightly lower numbers of growing degree days than millets and much lower numbers of growing degrees than rice. In contrast to foxtail and broomcorn millet, both wheat and barley also have a higher tolerance for frost and for sudden fluctuations in temperatures. Given their larger grain size and high yield (in terms of weight per panicle), these crops may also have had high appeal. In a risk prone environment like Haimenkou, wheat may quickly have passed the stage of being used as exotica to functioning as a risk buffering crop and soon thereafter a staple food.

While it is unknown what variety of breadwheat was cultivated by the inhabitants of Haimenkou it is reasonable to think that there may have been varieties of wheat that were cold adapted may have spread to southwest China at this time. Given the lack of necessary temperatures during the winter time to complete its growth cycle, it is possible that the varieties introduced to the Tibetan plateau and highland Southwest China may have been spring varieties of wheat and barley. In fact, the long delay underlying the transmission of wheat and barley to East Asia that is noted by both Jones et al. (2011) and Boivin et al. (2012) may have more to do with the fact that it was necessary to wait for the development of spring varieties that could be grown during the summer

months. The cooler winter temperatures of northern China and northern Central Asia may have created a huge impediment to the movement of winter varieties of wheat and barley throughout this region.

Interestingly, the spread of wheat and barley to East Asia takes place roughly two millennia after the movement of agriculture into northern Europe. Although it is possible that spring phenotypes were independently developed elsewhere, it is interesting to note that all movement of wheat and barley into East and Central Asia occurs after the movement of agriculture into northern Europe. Compared to other regions of the world, the varieties of wheat introduced to East Asia have a remarkable morphological homogeneity and these are generally described as being small and compact forms of bread wheat. This leads one to wonder if in fact this morphological homogeneity is not due to a single spring phenotype of wheat being originally introduced to China. Research on aDNA has potential to elucidate whether or not this was the case.

During later periods, winter varieties of wheat and barley may have been introduced to China. Today in many parts of southwest China the introduction of short season varieties of rice has allowed winter wheat to be grown as a catch crop further bolstering this region's productivity (Zhen 2000). It is unclear when the use of wheat as a double crop began in China. Some mentions of double cropping winter wheat or barley followed by millet are present in Fang Shengchi's *Agricultural Manual* that was composed in the first century (Shi 1956, 1974). Other scholars have argued that winter wheat was only introduced during the Tang dynasty (Bray 1984). A text found in a Western Han dynasty tomb in Yungang city in Jiangsu province,

contains some of the earliest historical mentions of winter wheat (Zhao and Chang 1999). No mention of double cropping either wheat (or barley) occurs prior to this date.

According to Bray (1984), this double cropping system is first mentioned shortly after the introduction of Champa rice and after the fall of the Northern Song Dynasty to the Mongols in 1127. A 12th century work (the *Ji Le Bian*) describes that this tradition of double cropping took off shortly after the movement of refugees from the Northwest to the Yangzi delta, the Dongting lake area and the Southeast coast (Zhuang 2009). This was also partially due to taxation reasons, as farmers were only taxed on rice harvest, and by growing a second season of wheat, large untaxable profits could be made. As a result, it seems reasonable to conclude that the earliest varieties of wheat and barley introduced to China were of a spring phenotype. This may explain why these domesticates were so readily adapted in the upland environments. In the lowlands where other already established crops fared well there was little incentive to adopt these new crops. It is possible that the potential for double cropping, afforded by the later introduction of winter varieties of wheat and barley played some role in the later popularity these crops came to know in historical times in lowland China.

In an environment where the potential for failure was high, exploiting crops with short growing seasons and high frost tolerance would have been important for early farmers. It is also important to note, however, that in most of the cases discussed in this paper, farmers diversified their strategies using a variety of crops with different temperature requirements and lengths of growing season. For instance, this was likely an important strategy for reducing risk on the Tibetan Plateau. In addition, it appears that the diet of these farmers was supplemented

significantly by foraging for wild foods such as the drolma (*Potentilla* sp.), wild strawberries and pine nuts. The archaeobotanical evidence from the Tibetan plateau shows that the early farmers on the plateau diversified their productive base and experimented with different food sources. Once pastoral animals were incorporated into the economy, a varied and dynamic range of dietary pursuits characterized the multi-resource pastoralism of Tibetan populations. Fishing, hunting, foraging, herding, and a diversified agricultural system were all parts of the subsistence economy. Further archaeobotanical analysis in this region holds out the promise to inform us about the strategies humans used to adapt their agricultural systems to one of the most challenging environments on earth.

Although situated in an area of much lower altitude than the Tibetan plateau, evidence from Haimenkou shows a similar pattern of risk reducing strategies, and a return to foraging for wild foods, namely *Chenopodium* sp. seems to have been important at one point in this site's history. Although both wheat and barley were known to the inhabitants of Haimenkou, wheat was favored over barley at the site, despite their similar growth habits. While the slightly smaller numbers of growing degree days required by spring varieties of wheat may have contributed to this pattern, it is possible that other factors such as taste could have come into play. Barley has a stronger more discernible nut-like flavor than wheat. Wheat, on the other hand, approaches the taste of rice in its neutral and clean flavor. It is thus possible that populations at Haimenkou could have favored wheat for cultural reasons relating to taste. Fuller and Castillo (In Prep) and Rowlands and Fuller (2009) have argued that cooking traditions of boiling and steaming were favored throughout much of East Asia in prehistory and can be opposed to traditions of baking found in India. How wheat was prepared at Haimenkou is a question that requires further

research, however, an initial evaluation of the data suggests that it was likely boiled, as no instruments relating to grinding wheat into flour or baking have been unearthed at the site. Further research is needed to determine how wheat fit into the culinary tradition of the inhabitants of the Qijia and related cultures as a whole.

That being the case, what were the factors that led to barley becoming the crop of preference on the Tibetan plateau? The answer to this question may lie in the potential presence of wild varieties of Tibetan barley. If the local wild Tibetan barley conferred its high altitude adapted genes to the already domesticated barley introduced from other areas of the world, then it is not surprising that local populations would have adopted this more ecologically adapted crop.

9.7 Epilogue: The Columbian Exchange and ecological adaptations in Southwest China

Following the introduction of wheat and barley, a number of other crops domesticated in other areas of the world also came to play important roles in agricultural strategies in southwest China. Short growing seasons, tolerance of poor soils and low numbers of growing degree days meant that during the 16th and 17th century, crops introduced from the New World were received well in Southwest China (Crosby 2003; M. Jones, et al. 2011). These include sweet potato, potato, maize and peanuts, which all extended the range of cultivation in upland southwest China and into the coast line. As early as 1959, Ho (1959: 184) has argued that this "second agricultural revolution" made the drylands and hills of northern and western China turn from virgin land to maize and sweet potato farms allowing a second demographic transition to take place.

Prior to the introduction of crops from the new world, it is worth briefly discussing sorghum. Sorghum was domesticated in sub-saharan Africa sometime between 4000-3000 BC (Dillon, et al. 2007; Fuller 2007; Weber 1998). Following this, it is conjectured that sorghum arrived in India around 2000 BC where it appears to have taken a long time to gain in importance (Weber 1998). Dillon et al. (2007) argue that sorghum was introduced to East Asia by approximately 400 AD. Initial discussions on the introduction of sorghum to East Asia were confused by the fact that millets and soybeans were misidentified in Yangshao period site reports as being *Sorghum bicolor* (L. Liu, et al. 2012). Textual evidence also suggests that sorghum was introduced only much later. Known as *shu shu* in Chinese, mentions of this crop do not appear in the literature until AD 300. However, it is unclear even if this mention is correct, or if the word actually referred to another crop (Bray 1984, 1994). The Chinese name of sorghum, *shu shu* (literally millet of Sichuan) implies that it may have first been grown extensively in Sichuan. Bray suggests, however, that sorghum (also known as *gao liang*) did not become important in China until rather late (the Yuan and Ming dynasty). Experiments carried out by Cardenas (1983) shows that modern varieties of sorghum require only an average of 1378 GDD (10°C base).

Maize appears to have arrived in China by the 16th century. An account by a Portuguese Priest Alvarez Semedo written in 1613 reports that maize was grown near Beijing for use by the emperor (Laufer 1907). Ho (1959) argues that this crop became popular throughout China after the Ming dynasty (1368-1644) and contributed to a huge population boom during the Qing. European explorers and botanists in the late 19th century found that corn was the primary crop grown throughout western Sichuan and Yunnan (Davies 1909; Wilson 1913) and noted that this crop was cultivated on land that was unsuitable for rice, particularly in hills and lower mountains

where slopes are too steep. The fact that maize was grown on poor land appears to have led to its classification as a food associated with poverty (and by extension ethnic minorities) (Anderson 1988; Gamble 1933).

Despite its low prestige, this crop's function as an apparent risk reducing or buffering crop and its ability to extend the land under cultivation led to its rapid adoption in Southwest China. Chen and Kung (2011) argue that maize played a causal effect on population growth in Ming and Qing China, and using instrumental modeling argue that maize accounted for a 21 % growth in population levels. Others, however, argue that an already growing population generated the need for the adoption of new crops and an expansion of agricultural land (Lee and Wang 1999; Perkins 1969). While the arrow of causality here is unclear, the fact that maize produces high yields, large grains and does not require substantial modification of the landscape could have contributed to its rapid uptake in southwest China.

Given the importance of the crop today, there is an extensive literature on the phonological properties of maize. Today hybrid varieties of corn require between 1500-1722 GDD to reach a harvesting stage (10°C base). For landraces grown in North America, Bockinsky and Kohler (2012) estimate that roughly 2000 GDD would have been required, although they note a minimum of 1400 and a maximum of 2400 GDD (10 ° C base). A map of the potential niche of maize shows that it was able to occupy a large area of southwest China, including much of upland Yunnan and western Sichuan (Figure 9.12). Given the similarity in the number of growing degree days required, sorghum can also be examined using the same map. The area covered by both is roughly similar to that of foxtail millet and thus ecology alone cannot explain

these crops adoption. It is thus possible that overall higher yield and grain size may have explained why these crops took off in southwest China.

China is now the world's second largest producer of maize, following the United States.

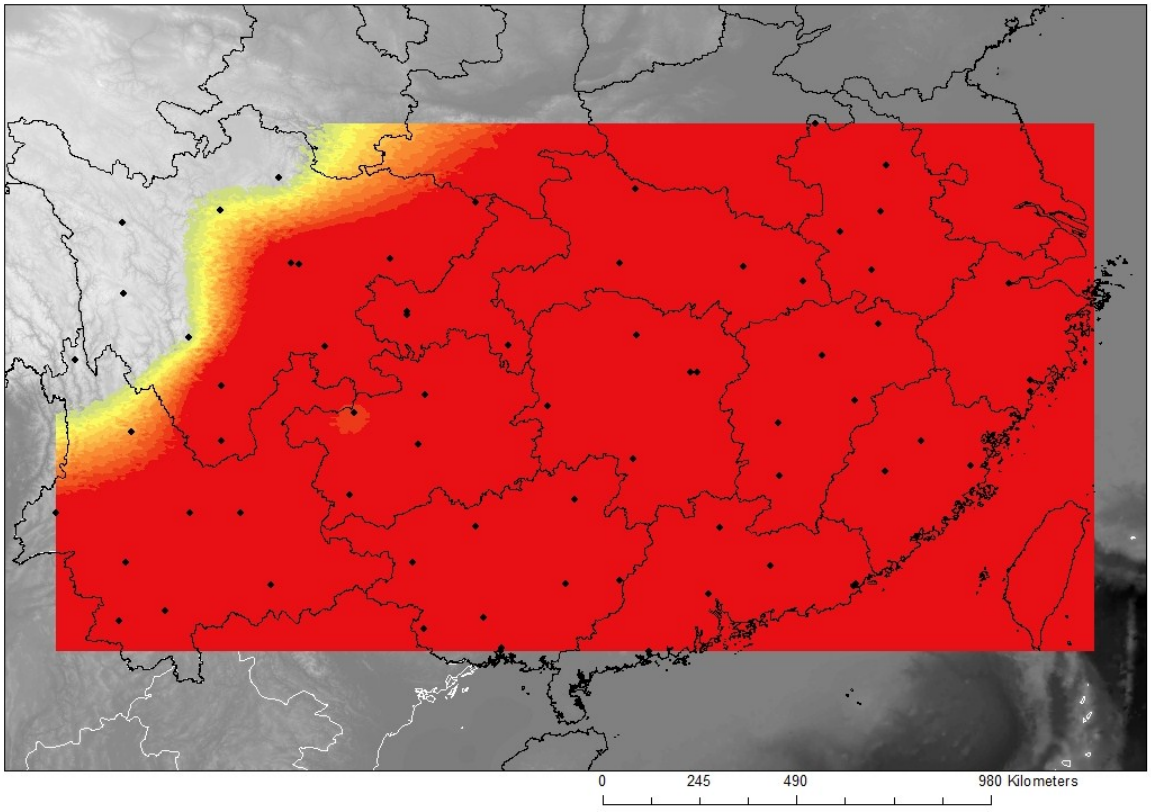

Figure 9.12 The potential distribution of sorghum (1378 GDD) and maize (1400-2400 GDD) across southwest China. Map created on a 10 °C base.

The sweet potato (*Ipomoea batatas*) is another crop native to the Americas that eventually became important in southwest China. There is some discussion as to where exactly sweet potato was domesticated. The oldest remains of sweet potatoes that can be hypothesized to be domesticated come from Peru and date to roughly 2000 BC (O'Brien 2000; O'Brien 1972),

however genetic studies point to Central America as being an original center of diversity (D. Zhang, et al. 2000). It was initially believed that sweet potato was introduced to Polynesia by the Portuguese during the 16th century, however recent evidence suggests that the sweet potato was introduced to Polynesia in prehistoric times (Green 2005; Kirch 2000). The earliest archaeological evidence for sweet potato comes from the Cook islands and dates to AD 1000 (Green 2005; Kirch 2000). Later finds include starch grains from New Zealand between AD 1400-1700 (Horrocks and Lawlor 2006). Remains of sweet potato have also been recovered from Hawaii (AD 1290-1430), and from Easter Island (AD 1526) (O'Brien 2000). Although some have suggested that this transfer may have taken place by boat and human migration (Green 2005), others (Montenegro, et al. 2008) argue that seed drift across oceans could have functioned as a mechanism for this crops dispersal.

The sweet potato is believed to have been introduced to China in 1594 by a Chinese business man from Luzon in the Philippines who brought this plant to the attention of the governor of Fujian during a year of famine (Zhang, et al. 2009). It thus appears to have initially been cultivated as a risk reducing crop.

Sweet Potato was adapted to a high altitude environment and poor soils. Sweet potato requires between 1400-1833 GDD (on a 15.5 °C base) (Villordon, et al. 2009). It also requires the soil to be at 15°C before they can start growth so limited to areas with more clement climate.
It can also be grown on steep slopes without substantial modification of the landscape, and as a result, increased the productivity of this region dramatically, by extending the range of cultivable soils (Chen and Kung 2011). Ho (1959) argues that this was motivated by the fact, that in the

18th century, rice had already reached its carrying capacity and farmers needed to expand into areas that could not be irrigated. Much like maize, however, up until recently there was an association between sweet potatoes and poverty.

Ho (1959) argues that when the peanut was first introduced to China it followed a very different trajectory and originally functioned as a luxury food. The peanut's ability to adapt to sandy soils and its nitrogen fixing properties meant that it slowly grew in popularity until 1929 it ranked 12th among all crops in China in terms of acreage (Simoons 1991).

Summary

A series of introductions of foreign crops modified the cultivated landscape in southwest China until it eventually took the modern form. The patterns of adoption of these crops were complex and both cultural and ecological conditions played important roles in dictating how these processes. Both wheat and barley presented important advantages to agriculturalists in highland southwest China as their ability to tolerate cold temperatures, frosts and their low requirements of growing degree days meant that they were able to occupy a wider niche than millets or rice. Large grain size may also have made these crops appealing to agriculturalists in the region. Although these crops could easily have been grown in the Sichuan Basin, cultural values and the sustainability of rice meant that they were not incorporated into the diet in this area in any important way until very recently. Not surprisingly barley became essential to allowing a settled lifestyle to be established on the Tibetan plateau. I argue that it is likely that gene flow with

native varieties of wild barley could have conferred favorable traits to populations of domesticated barley grown on the Tibetan Plateau, and this may have been why it was favored over wheat. Contrary to previous research, I argue that these crops were not delayed in their movement into East Asia because of a long growing season, but rather that it may have been necessary to wait for the development of a spring phenotype.

CHAPTER 10

CONCLUSION

The aim of this dissertation was to create models capable of outlining the series of constraints faced by ancient agriculturalists as they moved domesticates into the new and challenging ecological niches of Southwest China. Chapter 2 reviewed how the spread of agriculture has been approached in other areas of the world and discusses how two approaches: human behavioral ecology and niche construction have been used to understand change in ancient subsistence strategies. Although increasing numbers of studies have been applied to agricultural societies, I argue that optimal foragingmodels have been limited in their application to agricultural societies for the following reasons:

1.) Agriculture requires that people are tied to the land and cannot move to exploit new patches without first experiencing a year of failure. Thus before asking how humans optimize agricultural systems, it is imperative to first ask: how can humans ensure that they are able to carry out agriculture at all? Strategies for coping with new environments can include a.) changing the crop repertoire and planting the types of crops that are able to reach maturity in the ecological conditions humans have moved into; b.) carrying out risk management strategies (*sensu* minimizing the chance of loss or subsistence failure) such as diversification or intensification or c.) This can also be achieved by modifying the niche itself to fit the ecological requirements of the plant such as by supplying water via irrigation systems; d.) Changes can also be made to the growth conditions of the plant itself, by practicing indoor propagation of seedlings to shorten the growth season needed outdoors or by breeding cold or arid adapted varieties.

2.) Constructing models to identify optimal subsistence strategies in agricultural societies is difficult as a number of data points on return rate and labor investment can be difficult to calculate. Measures of kcal/hr are easy to estimate in foraging situations as returns can be calculated almost immediately. However in agricultural societies, trying to estimate the returns of a crop in kcal/hr is difficult because time and labor inputs can be highly variable according to local environmental conditions. While in foraging situations foods are processed shortly after gathering, in agricultural situations, there are long delays between labor input (the equivalent of search time) and between returns making it difficult to calculate kcal per hour and rank resources in a DBM type model. In most cases many months elapse before preparing the field, planting and the harvest. Daily field labor can also be difficult to account for. For instance, some fields require relatively little weeding or care, whereas others can require a substantial investment. In addition, in agricultural societies, specialization of the labor force has generally already occurred and opportunity cost is no longer an issue as farmers do not need to be actively involved in farming for the entirety of their day. In this specific context of this dissertation, return rate data on landraces of rice and millet were also difficult to acquire and as a result I was not able to draw these into a diet breadth type model.

Thus instead of asking whether or not humans behaved in an optimal or economically rational fashion, this dissertation focused on asking how humans dealt with the constraints imposed on them as they moved agriculture into new ecological niches. In order to assess the constraints ancient farmers faced as they moved agricultural products to new niches, I modelled the biological characteristics of the crops grown by humans. To do so, I worked with models capable

of determining these domesticate's niches (or the limits of the conditions that are able to sustain their growth). In chapter 3, I argued that ecological niche modeling can allow us to model these constraints and I outlined a series of methods to model the thermal niches of the domesticates that were moved into Southwest China. Chapter 4 gave a brief outline of the ecological niches that characterize Southwest China and reviewed the evidence for how ancient climate change impacted these ecological niches. In chapter 5, I reviewed the literature on the phenology of five different crops traditionally planted in southwest China. Chapter 6, 7, 8 and 9 investigated how three different sets of domesticates moved into southwest China at different times and investigated how restrictions imposed by the physiology of these domesticates led to differential patterns in their use and uptake. I argue that an approach informed that underscores the constraints and risk faced by ancient agriculturalists can provide insight into human adaptation in past agricultural strategies.

In the case of southwest China, both climate change and difficult local ecological conditions propelled humans to adapt their agricultural strategies to find sustainable solutions in the myriad of ecological niches that characterized this environment. In chapter 6, I argue that a dual cropping system of two different types of millet (broomcorn and foxtail millet) allowed ancient agriculturalists to alter their crop repertoire according to different environmental conditions. In addition, the short growing season of these two millets allowed populations to retain some degree of mobility and as a result may have had appeal to populations of hunter-gatherers who initially occupied this region. Although much more research is necessary before one can answer this question, it appears that this area was a zone of dynamic exchange between local hunter-gatherers and moving agriculturalists. The appearance of painted pottery manufactured in the

Majiayao heartland shows that some of the inhabitants of this region maintained close cultural ties to an agricultural heartland, however the persistence of microliths as well as the presence of local forms of pottery, suggests that populations other than migrating agriculturalists were involved in agriculture's uptake. Increased numbers of excavations in this region, will undoubtedly help highlight the role played by local hunter-gatherer populations in patterns of subsistence chnge. The continued presence of foods like *Chenopodium* and gathered fruits, combined with the presence of big game hunting, provides some clues as to what these people's subsistence strategies were composed of. In order to understand why an agricultural lifestyle replaced a hunter-gatherer lifestyle that had been successful for millennia, it is necessary to understand the lifestyles of the people who were present prior to the movement of agriculture into this region.

In chapter 7, I argue that a series of changes in agricultural strategies were necessary precursors to the spread of rice agriculture into southwest China, the first of which was the development of a temperate *O. japonica*. The second of these was the addition of foxtail millet, which allowed agriculturalists to move through difficult vertical terrain that could not easily be transformed into paddy environments and areas of cooler temperature where growing rice was a risky endeavor.

Different strategies were employed by humans inhabiting different environments and were influenced by local ecological conditions. For instance, in chapters 7 and 9, I argue that in highland Yunnan at Haimenkou where the risk for failure was high, humans initially diversified their subsistence base before finding a sustainable solution following the introduction of a western domesticate: wheat. In chapter 7, I argue that on the Chengdu plain, ecological

conditions supported a pattern of stability and the intensification of one resource, rice, which spurred population growth and led to this area being a center for the development of social complexity. The dual agricultural system composed of both rice and foxtail millet also served to buffer against risk in this region and as discussed in chapter 8 at one point in time (the late Baodun period), climate change led the inhabitants of the plain to diversify their diet in favor of these dryland crops.

The similarities in pottery repertoire and the presence of walled settlements hints at the close connections between the Baodun culture and cultures further to the East, namely in the Middle Yangzi. Their suddence appearance on the plain coupled with the absence of any clear antecendant leads me to believe that the Baodun culture is related to the migration of agriculturalists into this region. Future research is needed to determine the direction in which this spread took place. Three possibilites emerge for the direction of this spread: 1.) through the Three Gorges area, 2.) Via the north through the Hanshui Basin in Shanxi, and 3.) through the Wu River Basin in Guizhou. Fieldwork in these areas will help us determine which route these moving agriculturalists took and will allow us to identify the constraints faced by these moving agriculturalists as they moved through the highlands surrounding the Sichuan Basin. Further fieldwork in these regions will also help identify hunter-gatherer groups in this area and will allow us to understand the kinds of interactions moving agriculturalists and foragers had in southwest China during the spread of agriculture. My review of our understanding of forager/farmer interactions in Europe reveals that disentangling these two populations in the archaeological record can be difficult, and future research in China will need to bring a wide range of evidence to bear on this question: ranging from archaeobotanical and zooarchaeological

data, mortuary data, etc. to identify how identities and subsistence practices changed during this period of time.

In chapter 9, I argue that western domesticates' higher tolerance for frost and cold conditions extended the range of cultivation well beyond its original boundaries by buffering against the risk of agricultural failure. In addition, the large grain size and higher yield of these crops offered additional appeal. Compared to the lowlying plains of the Sichuan Basin and Central China, southwest Asian domesticates were more readily uptaken in these highland areas. While ecological reasons clearly played an important role in their uptake, cultural reasons may also have played an important role. In the highland Yunnan-Guizhou plateau, for the peoples who uptook an agricultural lifestyle (whether moving farmers or local foragers) rice does not appear to to have formed an essential part of their identity.

By creating testable hypotheses and by outlining the series of constraints, ecological niche modeling highlights the factors that led to change in human decision making with regards to agricultural strategies. This dissertation has investigated several different reasons for change in agricultural strategies during the spread of agriculture. The first of these relates to adaptations to change in climate. The second relates to adaptations to new landscapes as agriculturalists moved their crops into new environments. In addition principles of risk management and efficiency may also have motivated changes in agricultural strategies. Some changes in strategies were also prompted by social factors and in chapter 7, I argue that the need to extend the range of cultivation of a socially desirable crop, rice, led to important technological innovations. These occurred not only in the realm of crop breeding (i.e Champa rice) but also in the realm of

technological innovation (the creation of Titian terraces that extended the area in which rice could be grown dramatically).

In chapter 9, I argue that a combination of ecological characteristics and social characteristics mean that western domesticates were more easily adopted in areas that have traditionally been considered culturally peripheral. For instance, the Qijia expansion seems to be closely associated with a ceramic repertoire, burial traditions, and a food package, that signaled differences in identity to rice growers in lower altitudes.

The goal of this dissertation was to reconstruct how farmers moving agriculture into southwest China adapted their agricultural strategies to new and challenging environments and how local environmental conditions combined with the physiological properties of crops influenced their choice. As a result, this study has helped clarify some of the reasons underlying the delay in the spread of agriculture to this region. Through looking at these factors, I also sought to illuminate how cultural factors affected the uptake and determined patterns of use. More broadly, this dissertation sought to bring methods used in the field of ecological niche modeling and agronomy (growing degree days) to the study of ancient agricultural systems. I argued that creating models that can account for the series of constraints is an essential first step to using the framework of behavioral ecology in the study of ancient agriculture. The flotation samples analyzed from the Chengdu Plain and those reviewed from the published literature for the surrounding highlands formed the backbone against which I tested the predictions outlined by the constraints imposed by the physiological properties of crops and the ecological niches into which they were moved. Future research is needed to ascertain that the patterns seen in this

dissertation hold true. Although the Chengdu Plain was well sampled, the lack of systematic archaeobotanical research in other areas (the highlands of western Sichuan, the Yunnan-Guizhou plateau, the Tibetan plateau and Three Gorges) has limited our understanding of these processes and potential variability in patterns within this region. The introduction of systematic archaeobotany to excavations carried out in these areas will help us test these hypotheses. Although we were able to gain a rough idea of the timing of major cooling and drying events throughout this region by looking at multi-proxy paleoenvironmental data, these events occurred asynchronously across space and higher resolution is needed to determine how they impacted the myriad of different ecological niches in Southwest China. In addition, additional modeling is necessary to determine how these changes affected surface temperatures and ultimately the niches within which crops were able to grow.

Finally, in order to go beyond examining constraining factors to constructing models that can predict optimal behavior, it is necessary to gain additional data to input into these models. Firstly, a better understanding of the phenology of the crops grown in this region is needed. In particular, more research is needed on the landraces of crops that were grown in this region. While estimates derived from modern cultivars can give us a rough idea of how these crops differed in the niches they were able to occupy, a greater understanding of the variability among landraces is needed to lend further support to this study. One major pitfall of this dissertation was that to date, almost no experimental studies have been carried out on the growing degree days required by these varieties.In order to gather this data, I am currently carrying out experimental plots of landraces in order to isolate their phenology properties, in collaboration with an NGO, Gene Campaign, based in Himalayan India. In addition to helping understand the role of plant biology

in determining past agricultural patterns, this collaboration with an NGO will also contribute useful data for studies of modern farming practice, and will give local farmers accurate data on the feasibility of planting these varieties.

Finally, plants are responsive to a variety of other abiotic factors in addition to temperature: these include soil quality, rainfall, and nutrients. These experimental plots will also allow us to gather data on these other abiotic factors that can drawn into more detailed species distribution models. These experimental studies will also allow us to gatherer essential data on labor input and yields, which are necessary to draw this data into a diet breadth model.

Overall, the perspective inspired by behavioral ecology in this dissertation has allowed me to identify behavioral changes in agricultural strategies that may have been chosen by farmers based on contemporary ecological factors, plant physiology and social factors. I believe that by identifying these constraints and by examining how humans responded to them, we can gain important insights into how humans have adapted and reinvented their agricultural strategies in the past, not only in China but around the world.

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Appendix A: Creation of Paleobot.org

In order to address the diverse online needs of the archaeobotany community, in addition to housing the specimens discussed in this dissertation, Christina Warinner and I (Warinner, et al. 2011) developed Paleobot.org. Paleobot.org is a collaborative, open-access website that allows individual researchers to share reference collection images and data, as well as images of unidentified remains, using a free online platform. During a survey carried out my Naomi Miller (Archaeobotany Questionnaire 2010), one of the major challenges listed by archaeobotanists was the lack of identification tools and reference collection images for specific regions and overall. When asked what would facilitate or enhance their own archaeobotanical research in a practical or intellectual way, respondents listed the development of online identification databases as the single-most desired resource. A strong desire for a website dedicated to the identification of unknown specimens was also expressed. At present, archaeobotanists most frequently solicit assistance with difficult identifications by disseminating images over email listservs, but email is poorly suited for such purposes and is ill-equipped to handle large image files and complicated discussion threads involving multiple individuals. It became clear that a dedicated online source that could host high quality images, as well as curate associated metadata such as field notes, site information, and comments and discussion, would greatly benefit the archaeobotany community. The goal of Paleobot.org was to bring together a large academic community of archaeobotanists to share data, information, and expertise for the common purpose of improving the identification of archaeobotanical specimens. As with other online resources, the goal of Paleobot.org was not to duplicate the function of a herbarium, reference collection specimens, or slides. Rather, the aim of the website is to assist researchers with preliminary identifications, particularly for poorly studied regions such as Southern China, which can then be confirmed with the use of herbaria,

literature, or the assistance of a specialist. Paleobot.org is not a replacement for herbaria or plant taxonomists, but rather a way to use them more effectively.

Paleobot.org was developed by David Goode (Warinner, et al. 2011) using the open source content management platform Drupal, and the site was officially launched on July 1, 2010. Paleobot.org is distinguished by a number of user-friendly features that facilitate scholarly communication and collaborative research, including: open-access viewing and submission, the support of multiple data types, an unidentified forum, assistance with copyright retention, and the ability to create personal research profiles.

Archaeobotanists work with a wide variety of macro- and microbotanical remains and require access to large reference collections to be able to effectively and accurately identify specimens. Paleobot.org curates images of the most commonly analyzed types of macro- and microbotanical remains, including macrobotanical remains, pollen, phytoliths, and starches, to facilitate this process. In addition to image files, C, N, O, & H isotopic data may also be uploaded.

All archaeobotanists, at one time or another, encounter a specimen that eludes identification. Paleobot.org provides an unidentified forum where researchers can upload images of unidentified specimens and solicit advice from fellow archaeobotanists. Comments and discussion threads are curated with the image for easy reference and may later serve as an archived source of information for similar specimens.

Reference collections take considerable time and effort to construct. For an open-access online database to be successful, it was essential that contributors are properly credited for their reference collection images. In creating the website we took a number of measures to ensure that the authors of these images are given proper citation and acknowledgment for their work. First, all users retain copyright over the personal research images they upload to the site. This differs from some other sites where the hosting institution, for example a university, controls the copyright of any posted material. Clear copyright and fair use guidelines are posted on the website, and in order to ensure that images placed on Paleobot.org cannot be used in presentations or publications without proper image credit, we employ software that automatically embeds copyright information on all images uploaded to the site. Under the terms of fair use, users agree to allow individuals to use content and images from Paleobot.org for their own identification purposes and in non-commercial scholarly and educational materials without special permission as long as they include proper photo credit and citation.

Contributors of images to the website also gain exposure through the creation of a personal research profile on our Contributors page. Although anyone may search the online collections, contributors to the website are required to create a personal research profile before they submit images to the website. Following the creation of a profile, each contributor's photograph, institutional affiliation, contact email address, research website links, and research interests will be featured on the Contributors tab of the website. We anticipate that this page will serve as a hub for connecting researchers around the world

Appendix B : Sample Provenience Information

Table B.1 Sample Provenience Information

Flotation No.	Site name	Unit number	Layer	Weight	Volume (L)	Date floated
1	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST1	2	9206	16	11/7/2009
2	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST2	2	7714	12	12/7/2009
3	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST2	4	9027	13	12/7/2009
4	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST2	2	9187	11	12/7/2009
5	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST2	4	7550	11.5	15/7/2008
6	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSSH1		8309	12	12/7/2009
7	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSSH1		8643	9	13/7/2009
8	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSSH1		8050	10.5	13/7/2009
9	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST1	2	7976	13	13/7/2009
10	Pixian Sandaoyan Songjiaheba 郫县三道堰宋家河坝	2009PSST1	2	8365	12	14/7/2009
11	Pixian Shiweigan 郫县石桅杆	2009PGLT1	3	7366	12	14/7/2009
12	Pixian Shiweigan 郫县石桅杆	2009PGLT1	5	8877	13	14/7/2009
20	Pixian Shiweigan 郫县石桅杆	2009PGLT1	5	18646	13	19/7/2009
46	Xinjian Xinping Baodun 新津新平镇宝墩遗址	2009CXBIVT2426	5	22134	17	30/6/2010

Table B.1 (Continued)						
47	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT1830	3	29698	23	30/6/2010
48	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	3下	41068	30.5	1/7/2010
49	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2426	4	19465	15	1/7/2010
50	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	4下H1	16509	16	1/7/2010
51	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	4下H2	18400	16	1/7/2010
52	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	H8	18327	15.5	1/7/2010
53	Xinjian Xinping Baodun 新津县新平镇宝墩	2009CXBIVT2431	3	28510	22	2/7/2010
54	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2426	5下H6	20249	19	2/7/2010
55	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	H11	34676	29	2/7/2010
56	Xinjian Xinping Baodun 新津县新平镇宝墩	2009CXBIVT1830	4下H3	18764	18	2/7/2010
57	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2431	5	15451	14	2/7/2010
58	Xinjian Xinping Baodun 新津县新平镇宝墩遗址	2009CXBIVT2341	4下H9	17400	16	3/7/2010
59	Xinjian Xinping Baodun 新津县新平镇宝墩	2009CXBIVT1830	5	25869	20.5	3/7/2010
60	Xinjian Xinping Baodun 新津县新平镇宝墩	2009CXBIVT2426	3	37808	31.5	3/7/2010
61	Pixian Bolocun Erzu 郫县菠萝村二组	T6H90	5B下	36731	32	3/7/2010

Table B.1 Continued						
62	Pixian Bolocun Erzu 郫县菠萝村二组	T6H49	5B下	17357	7	5/7/2010
63	Pixian Bolocun Erzu 郫县菠萝村二组	T2	5B下	17280	14	5/7/2010
64	Pixian Bolocun Erzu 郫县菠萝村二组	T3	5B下H13	18561	15	5/7/2010
65	Pixian Bolocun Erzu 郫县菠萝村二组	T10	5BH31	15421	13	5/7/2010
66	Pixian Bolocun Erzu 郫县菠萝村二组	T5	5B下H82	33114	27	5/7/2010
67	Pixian Bolocun Erzu 郫县菠萝村二组	09CPBT1	5A	27744	21	5/7/2010
68	Pixian Bolocun Erzu 郫县菠萝村二组	T10	5BH32	31063	27.5	5/7/2010
69	Pixian Bolocun Erzu 郫县菠萝村二组	T5	5B下H82	11297	9.5	5/7/2010
70	Pixian Bolocun Erzu 郫县菠萝村二组	T2	5B下	25019	21	5/7/2010
71	Pixian Bolocun Erzu 郫县菠萝村二组	T2	5B下	25483	21	5/7/2010
72	Pixian Bolocun Erzu 郫县菠萝村二组	T7 5B下	H43	18802	16	5/7/2010
73	Pixian Bolocun Erzu 郫县菠萝村二组	T8	5B下	25293	21.5	6/7/2010
74	Pixian Bolocun Erzu 郫县菠萝村二组	09CPBT1	6	9508	8.5	6/7/2010
75	Pixian Bolocun Erzu 郫县菠萝村二组	09CPBT1	5B	7230	5	6/7/2010
76	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H16	39297	28.5	6/7/2010

Table B.1 Continued						
77	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H17	22701	17	6/7/2010
78	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H11	20557	16.5	6/7/2010
79	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXSTN2E5	7	19376	15	6/7/2010
80	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXSTN1E5	7	44263	33.5	7/7/2010
81	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H15	26099	20	7/7/2010
82	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H13	18104	14	7/7/2010
83	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H17	18837	15	7/7/2010
84	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H16	18317	13	7/7/2010
85	Xindu Sanhehuayuan Jiuzu 新都三河花园九组	2010CXS	H15	27983	16	7/7/2010
86	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJ	VTH6999	1313	1L	7/7/2010
87	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	Y214	1241	<1	7/7/2010
88	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1292- VIT1191	5	9868	9	7/7/2010
89	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	H7038	10699	9	7/7/2010
90	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	Y235	6390	5.5	7/7/2010
91	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	H7035	10394	9	7/7/2010

Table B.1 Continued						
92	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1092-VIT0991	5	10639	10	7/7/2010
93	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	H7036	4688	4	7/7/2010
94	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT	H6986	4349	4.5	7/7/2010
95	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJ	H7006	5106	4.5	7/7/2010
117	Zhonghai Guoji Shequ 中海国际社区		H30	53873	43	9/7/2010
118	Zhonghai Guoji Shequ 中海国际社区		H26	39434	29	9/7/2010
119	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1092-T0991	6下	9995	9	11/7/2010
120	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1090-T0989	6下	15239	15	11/7/2010
121	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1293-T1192	5下	17547	16	11/7/2010
122	Qingyang Xingchengjian Gongdi 青羊兴城建工地	2008CQJVIT1290-VIT1189	6	15372	13	11/7/2010
123	Jinsha Yizhi Taiji Huayulang Gongdi 金沙遗址泰基·花语廊工地		H4237	60520	44	11/7/2010
124	Jinsha Yizhi Taiji Huayulang Gongdi 金沙遗址泰基·花语廊工地		H4239	13011	11	11/7/2010
125	Zhuxin Kejiyuan Jinnicun 5-6 Zu 铸信科技园，金牛村5-6组	2006CJT	H4925	26450	23	13/7/2010
126	Zhuxin Kejiyuan Jinnicun 5-6 Zu 铸信科技园，金牛村5-6组	2006CJT	H4936	26208	21	13/7/2010
127	Zhuxin Kejiyuan Jinnicun 5-6 Zu 铸信科技园，金牛村5-6组	2006CJT	H4926	53091	42	13/7/2010

Table B.1 Continued						
136	Jinsha Yizhi Languang Yongjinwan 金沙遗址蓝光雍锦湾	2005CQJ	H30	19894	17	14/7/2010
137	Jinsha Yizhi Languang Yongjinwan 金沙遗址蓝光雍锦湾	2005CQJ	H4559	18055	16	14/7/2010
138	Jinsha Yizhi Languang Yongjinwan 金沙遗址蓝光雍锦湾	2005CQJT2686	H4181	27849	23	14/7/2010
139	Jinsha Yizhi Languang Yongjinwan 金沙遗址蓝光雍锦湾	2005CQJ	H4559	29840	24.5	15/7/2010
140	Jinsha Yizhi Languang Yongjinwan 金沙遗址蓝光雍锦湾		H4181	28472	21.5	15/7/2010
141	Jinsha Yangguang Didai 金沙阳光地带	2004CJY	H1349	64979	47	15/7/2010
142	Jinnuiqu Guotuju Langjia Qi, Bazu Chai Qianfang 金牛区国土局郎家七、八组拆迁房	2005CJY	H2431	16785	13	15/7/2010
143	Jinnuiqu Guotuju Langjia Qi, Bazu Chai Qianfang 金牛区国土局郎家七、八组拆迁房	2005CJY	H2431	23697	16	15/7/2010
144	Jinnuiqu Hongsecun 金牛区红色村	2006CQJ	H4600	14699	10	3/8/2010
145	Jinniuqu Hongsecun 金牛区红色村	2006CQJXIXT4548-T4447	H4246	17719	14	3/8/2010
146	Jinsha Yizhi Langjia Yizu Taiji Huayulang 金沙遗址郎家一组泰基花语廊工地	2006CQJ	H4239	14774	13	3/8/2010
149	Xizang Changdu Karuo 西藏昌都卡若	02XCKT7东壁3下H4	L3		1	
150	Xizang Changdu Karuo 西藏昌都卡若	02XCKT7H2	H2		1	
151	Xizang Changdu Karuo 西藏昌都卡若	T7	L3		1	
152	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1485	H1	17865	15	5/12/2010
153	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1485	L4	20651	17	
154	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1685	L3	20298	16	
161	Guiyuanqiao 桂圆桥	TN01E05(3)B下	H31	16603	16	6/12/2010
162	Guiyuanqiao 桂圆桥	2009SGTN13W08(4)下	Z1	8111	7	6/12/2010

Table B.1 Continued						
163	Guiyuanqiao 桂圆桥	2009SGTN03W01(4)	Red earth	14877	11.5	6/12/2010
164	Guiyuanqiao 桂圆桥	2009SGTN01E05(4)		18772	15	6/12/2010
165	Guiyuanqiao 桂圆桥	2009?	H43	17031	14	6/12/2010
166	Guiyuanqiao 桂圆桥	无纪录		16464	14	6/12/2010
167	Guiyuanqiao 桂圆桥	2009SG?	H12南部上层	9140	7	6/12/2010
168	Guiyuanqiao 桂圆桥	2009SG	F1灶膛	17776	14	6/12/2010
169	Guiyuanqiao 桂圆桥	2009SGT0401	H12(3)下	17605	14	6/12/2010
170	Guiyuanqiao 桂圆桥	2009SG	H9	17524	14	7/12/2010
171	Guiyuanqiao 桂圆桥	2009SG	Z3	18497	16	7/12/2010
172	Guiyuanqiao 桂圆桥	2009SG	H11	14470	14	7/12/2010
173	Guiyuanqiao 桂圆桥	2009SGTN03E03(4)	探方东南角	15548	12	7/12/2010
174	Guiyuanqiao 桂圆桥	2009SGTN01E05(3B)下	H31	16751	15	7/12/2010
175	Guiyuanqiao 桂圆桥	2009SG	H12	18387	15	7/12/2010
176	Guiyuanqiao 桂圆桥	2009SG	H9下层	18081	14	7/12/2010
177	Guiyuanqiao 桂圆桥	2009SG	H20(3)黑灰土	16730	13	7/12/2010
178	Guiyuanqiao 桂圆桥	2009SG	H32	9239	7	7/12/2010
185	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1586	2层下H2	34710	27	7/12/2010
186	Xizang Changdu Karuo 西藏昌都卡若	02XCKT7K1	东壁下2层下K1		<1	7/12/2010
187	Xizang Changdu Karuo 西藏昌都卡若	02XCKT7	F1	842	<1	7/12/2010
188	Xizang Ali Dingdun 西藏阿里丁东	str1 /99	F1		<1	7/12/2010
189	Xizang Ali Dingdun 西藏阿里丁东	STR4/HEARTH			<1	7/12/2010
190	Xizang Changdu Karuo 西藏昌都卡若	02XCKT7H1	H1		<1	7/12/2010
191	Guiyuanqiao 桂圆桥	2009SG	H12坑底	8300	6	27/7/2011
192	Guiyuanqiao 桂圆桥		H12南部下层	9919	6	27/7/2011
193	Guiyuanqiao 桂圆桥	2009SGTN01E04及南括方	Y2	19248	15	27/7/2011

Table B.1 (Continued)						
194	Guiyuanqiao 桂圆桥	2009SG	H9	17250	13	27/7/2011
195	Guiyuanqiao 桂圆桥	2009SG	H33	15627	13	27/7/2011
196	Guiyuanqiao 桂圆桥	2009SGT0401	③	9541	6	27/7/2011
197	Guiyuanqiao 桂圆桥	2009SGTN02E04	⑥	19073	14	27/7/2011
198	Guiyuanqiao 桂圆桥	2009SG	H25	17678	15	27/7/2011
199	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1585	5	32438	26	5/3/2011
200	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1485	4	36316	27	5/3/2011
201	Xinjian Baodun 新津宝墩遗址	2010CXBMTG1	5	22240	17	5/3/2011
202	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1485 (4)	H1	26469	23	5/3/2011
203	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3411	4	60258	45.5	5/3/2011
204	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3211	H10	19867	18	6/3/2011
205	Xinjian Baodun 新津宝墩遗址	2010CXBIIIT1486	4	35100	26	7/3/2011
206	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3511	G4	30785	21	7/3/2011
207	Xinjian Baodun 新津宝墩遗址	2010CXBIVT2324	H9	22878	16	7/3/2011
208	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3628	G5①	21443	18	7/3/2011
209	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3010	H13	19934	17	15/3/2011
210	Xinjian Baodun 新津宝墩遗址	2010CCBIVT3212	⑤	30333	23	16/3/2011
211	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3310	G3	22972	20	17/03/2011
212	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3312	⑦	26289	22	17/03/2011
213	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3411	H17	18686	16	19/3/2011
214	Xinjian Baodun 新津宝墩遗址	2010CXBIVT2121	H5	32817	34	19/03/2011
215	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3209	H21	16656	15	19/03/2011
216	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3412	H14	16388	16	19/03/2011
217	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3212	H7	11202	11	19/03/2011
218	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3311	H19	8475	8	20/03/2011
219	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3210	⑥	17426	15	20/03/2011
220	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3411	H18	19256	18	20/03/2011

Table B.1 (Continued)						
221	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3628	H23	16321	14	20/03/2011
222	Xinjian Baodun 新津宝墩遗址	2010CXBIVT3209	H8	30756	24	20/03/2011
223	Kyung-Lung Silver Castle 穹隆银城	KL1	S616	1954	3	21/03/2011
224	Kyung-Lung Silver Castle 穹隆银城	KLB区北端		853	1.5	21/03/2011
225	Kyung-Lung Silver Castle 穹隆银城	KLH	S66	352	1	21/03/2011

Appendix C: Identifications of Flotation Samples

The following pages present the data table for the results of the flotation sample analysis.

Table C1 Baodun Samples

Baodun Samples	**59**	**46**	**54**	**57**	**50**	**56**	**55**	**52**	**51**
Litres	20.5	17	19	14	16	18	29	15.5	16
Wood (g)	0.124	1.971	2.767	0.254	0.074	0.417	0.939	0.606	0.48
Cereals									
Oryza Whole		0	3	6			3	1	3
Oryza frag.	1	10	15	31	4	13	15	24	29
Oryza Spikelets	3	25	25	48	37	0	207	133	1
Oryza Immature			1				1	1	
Oryza Embryo				3			6	4	
Oryza Whole + frag	1	10	18	37	4	13	18	25	32
Setaria italica Whole		3	1				5	2	
Setaria italica frag.		1			2				
Setaria italica whole+frag	0	4	1	0	2	0	5	2	0
Immature *Setaria*							6		1
Total cereal	0	4	1	3	2	0	11	6	0
Coix									
Cf. *Coix* Involucral bract fragments		9	5	2				2	
Upland Weeds									
Wild *Setaria* whole + frag		3		1	1		2	3	1
Caryophyllaceae									
Digitaria whole+ frag			1	1			8	3	2
Calamagrostis/Eragrostis/Aira		1					5	2	2
Panicoid cf. *Andropogon* type 4							3		
cf. *Hackelochloa* frag.		5	3					1	
cf. *Hackelocloa* whole									
cf. immature *Hackleocloa*									
Eleusine Indica							2		
Chenopodium			1					1	
Chenopodium frag.		1	3	4	7		17	13	
Solanum whole									
Solanum Frag.									
Galium									1
Hyoscamus								1	1
Xanthium									
cf. *Verbena*							1	1	
Perilla									
Lamiaceae cf. *Stachys*									
Pulses									
Vicia sp.		10	39	2	1	1	2		
Vigna cf. *angularis*							1		
Vigna cf. *radiate*									
Undet fabaceae									

Table C.1 Baodun samples (Continued)	**59**	**46**	**54**	**57**	**50**	**56**	**55**	**52**	**51**
Wetland Weeds									
Fimbristylis whole silificified		7	17			4	2	1	
Fimbristylis frag silicified		100	47	4		55	47	5	
Fimbristylis (small type)			1			1		1	
cf. *Equisetum* plant sections		10	22				15	5	
Upland and Wetland Weeds									
Poaceae cf. *Miscanthus*			39						
Echinochloa			1	1			3	1	3
Undet Millet whole+ fragments	1	3	10	1	1		3	2	
Undet Panicoid grass type 3									
Wild Poaceae Whole + fragments									
Polygonum persicaria type						1			
Polygonaceae				1					
Potamogeton									
cf. Cyperaceae cotelydon		4			1		1	8	
cf. *Scirpus* pericarp						1			
cf. *Carex* type									
cf. *Cyperus*							1		
Fruits									
Cratageus									
Sambucus				1					
Unidentified seeds	1	2		1		2	5	8	7
Undet nutshell fragments								7	
Uncarbonized seeds	4					1	8	3	

Table C.1 Baodun Samples (Continued)	**58**	**212**	**220**	**213**	**48**	**49**	**214**
Litres	16	22	18	16	30.5	15	34
Wood (g)	0.847	0.1198	2.9418	4.2038	0.004	0.05	2.417
Cereals							
Oryza Whole			2				3
Oryza frag.	21		2	3		6	24
Oryza Spikelets	107	25	76		0	0	2
Oryza Immature							
Oryza Embryo	5		3	3			5
Oryza Whole + frag	21	0	4	3		6	27
Setaria italica Whole			4	1			4
Setaria italica frag.	1			1			
Setaria italica whole+frag	1	0	4	2	0	0	4
Immature *Setaria*	1						
Total cereal	6	0	7	5	0	0	9
Coix							
c.f *Coix* Involucral bract fragments			2	2			7
Upland Weeds							
Wild *Setaria* whole + frag	2						4
Caryophyllaceae						1	
Digitaria whole+ frag	4	6	2			1	
Calamagrostis/Eragrostis/Aira	7						
Panicoid cf. *Andropogon* type 4							
cf. *Hackelochloa* frag.		2	15	12	0	0	50
cf. *Hackelocloa* whole							
cf. immature *Hackleocloa*							
Eleusine Indica				1		6	
Chenopodium							
Chenopodium frag.	9	2	2	1			2
Solanum whole							
Solanum Frag.							1
Galium							
Hyoscamus							
Xanthium							
cf. *Verbena*	1		1				
Pulses							
Vicia sp.	3		1		0	0	1
Vigna cf. *angularis*							
Vigna cf. *radiata*							
Undet fabaceae							

Table C.1 Baodun Samples (Continued)	**58**	**212**	**220**	**213**	**48**	**49**	**214**
Wetland Weeds							
Fimbristylis whole silificified			2	1	0	0	3
Fimbristylis frag silicified	23	4	13	2		1	25
Fimbristylis (small type)							
cf. *Equisetum* plant sections	1	1	1				2
Upland and Wetland Weeds							
Poaceae cf. *Miscanthus*							
Echinochloa		2			0	0	4
Undet Millet whole+ fragments	1				1	0	7
Undet Panicoid grass type 3		1	1				2
Wild Poaceae Whole + fragments							
Polygonum persicaria type							
Polygonaceae		3					
Potamogeton							
cf. Cyperaceae cotelydon							
cf. *Scirpus* pericarp							
cf. *Carex* type				1			1
cf. *Cyperus*							
Fruits							
Cratageus							1
Sambucus							
Unidentified seeds	4		1		1	1	8
Undet nutshell fragments				1			
Uncarbonized seeds	1	22	2	2		5	1

Table C.1 Baodun Samples (Continued)	**204**	**185**	**216**	**207**	**221**	**209**
Litres	18	27	16	16	14	17
Wood (g)	1.4852	11.12	2.6325	0.2967	2.8366	5.2324
Cereals						
Oryza Whole	1	7	1		1	
Oryza frag.	5	63	29	1	10	19
Oryza Spikelets	35	1		19	3	5
Oryza Immature						
Oryza Embryo		4	2			7
Oryza Whole + frag	6	70	30	1	11	19
Setaria italica Whole						
Setaria italica frag.		1	1			
Setaria italica whole+frag	0	1	1	0	0	0
Immature *Setaria*						
Total cereal	0	5	3	0	0	7
Coix						
c.f *Coix* Involucral bract fragments	14	69	1		15	25
Upland Weeds						
Wild *Setaria* whole + frag						
Caryophyllaceae						
Digitaria whole+ frag						
Calamagrostis/Eragrostis/Aira						
Panicoid c.f Andropogon type 4						
cf. *Hackelochloa* frag.	8	400	15	0	1	9
cf. *Hackelocloa* whole		5				
cf. immature *Hackleocloa*		21				2
Eleusine indica						
Chenopodium			1			
Chenopodium frag.						
Solanum whole						
Solanum Frag.						
Galium						
Hyoscamus						
Xanthium						
cf. *Verbena*						
Perilla	1					
Lamiaceae cf. stachys						
Pulses						
Vicia sp.	1	1	0	0	0	0
Vigna cf. *angularis*						
Vigna cf. *radiate*						
Undet fabaceae						

Table C.1 Baodun Samples (Continued)	**204**	**185**	**216**	**207**	**221**	**209**
Wetland Weeds						
Fimbristylis whole silificified	55	70	13		7	1
Fimbristylis frag silicified	70	177	11		54	17
Fimbristylis (small type)	2					
Cf. *Equisetum* plant sections	7	2	2		1	2
Upland and Wetland Weeds						
Poaceae cf. *Miscanthus*						
Echinochloa	0	3	0	0	1	0
Undet Millet whole+ fragments	0	3	0	0	0	2
Undet Panicoid grass type 3						
Wild Poaceae Whole + fragments						
Polygonum persicaria type						
Polygonaceae					1	
Potamogeton					1	
Cf. Cyperaceae cotelydon						
Cf. *Scirpus* pericarp						
Cf. *Carex* type						
Cf. *Cyperus*						
Fruits						
Cratageus						
Sambucus						
Unidentified seeds	4					1
Undet nutshell fragments						
Uncarbonized seeds	1	3	2	3		2

Table C.1 Baodun Samples (Continued)	**205**	**219**	**202**	**200**	**217**	**206**	**222**	**215**
Litres	26	15	38	27	11	21	24	15
Wood (g)	0.10	1.53	10.0	0.029	0.29	0	0.039	5.9
Cereals								
Oryza Whole		2	1		9			4
Oryza frag.		17	8		58		5	23
Oryza Spikelets	3	10		95	13		7	8
Oryza Immature								
Oryza Embryo		8	1		3			3
Oryza Whole + frag	0	19	9	0	67	0	5	27
Setaria italica Whole					1			
Setaria italica frag.								
Setaria italica whole+frag	0	0	0	0	1	0	0	0
Immature *Setaria*								
Total cereal	0	8	1	0	4	0	0	3
Coix					1			
cf. *Coix* Involucral bract fragments		5	114		4			4
Upland Weeds								
Wild *Setaria* whole + frag								1
Caryophyllaceae								
Digitaria whole+ frag		6						
Calamagrostis/Eragrostis/Aira								
Panicoid cf. *Andropogon* type 4								
cf. *Hackelochloa* frag.		56	147		10		2	1
cf. *Hackelocloa* whole			2		1			
cf. immature *Hackleocloa*								
Eleusine indica								
Chenopodium								1
Chenopodium frag.		1			1			
Solanum whole								
Solanum Frag.								
Galium								
Hyoscamus								
Xanthium								1
cf. *Verbena*								
Perilla								1
Lamiaceae cf. *Stachys*		1	1		1			
Pulses								
Vicia sp.	0	1						
Vigna cf. *angularis*								
Vigna cf. *radiate*								
Undet fabaceae					1			

Table C.1 Baodun Samples (Continued)	**205**	**219**	**202**	**200**	**217**	**206**	**222**	**215**
Wetland Weeds								
Fimbristylis whole silificified		1	35		3		1	
Fimbristylis frag silicified		16	131		8			8
Fimbristylis (small type)								
Cf. *Equisetum* plant sections		7	12					1
Upland and Wetland Weeds								
Poaceae cf. *Miscanthus*								
Echinochloa			1					
Undet Millet whole+ fragments		3						
Undet Panicoid grass type 3			2				1	1
Wild Poaceae Whole + fragments								
Polygonum persicaria type								
Polygonaceae								
Potamogeton								
Cf. Cyperaceae cotelydon								
Cf. *Scirpus* pericarp								1
Cf. *Carex* type								
Cf. *Cyperus*								
Fruits								
Cratageus								
Sambucus								
Unidentified seeds		5	2		2			1
Undet nutshell fragments								
Uncarbonized seeds	1		7		2	1	1	

Table C.1 Baodun Samples (Continued)	**218**	**211**	**154**	**153**	**53**	**60**	**203**	**201**
Litres	8	20	16	17	22	31	45.5	17
Wood (g)	2.41	0.390	0.022	0.00	0.02	0.14	0.69	0.0
Cereals								
Oryza Whole				0				
Oryza frag.				0	1	2	8	
Oryza Spikelets				0	2	5	0	1
Oryza Immature				0				
Oryza Embryo	1			0			2	
Oryza Whole + frag	0	0	0	0	1	2	8	0
Setaria italica Whole				0				1
Setaria italica frag.				0				
Setaria italica whole+frag	0	0	0	0	0	0	0	1
Immature *Setaria*				0				
Total cereal	1	0	0	0	0	0	2	1
Coix				0				
c.f *Coix* Involucral bract fragments	17	3		0				
Upland Weeds								
Wild *Setaria* whole + frag				0				1
Caryophyllaceae				0				
Digitaria whole+ frag				0				
Calamagrostis/Eragrostis/Aira				0				
Panicoid cf. *Andropogon* type 4				0				
cf. *Hackelochloa* frag.	20	2		0				
cf. *Hackelocloa* whole				0				
cf. immature *Hackleocloa*				0				
Eleusine indica				0		1		
Chenopodium				0				
Chenopodium frag.				0		1		
Solanum whole				0				
Solanum Frag.				0				
Galium				0				
Hyoscamus				0				
Xanthium				0				
cf. *Verbena*				0				
Perilla								
Lamiaceae cf. *Stachys*				0			2	
Pulses								
Vicia sp.				0				
Vigna cf. *angularis*				0			1	
Vigna cf. *radiate*				0			1	
Undet Fabaceae				0				

Table C.1 Baodun Samples (Continued)	**218**	**211**	**154**	**153**	**53**	**60**	**203**	**201**
Wetland Weeds								
Fimbristylis whole silificified	15			0				
Fimbristylis frag silicified		1		0				
Fimbristylis (small type)				0				
Cf. *Equisetum* plant sections	7			0				
Upland and Wetland Weeds								
Poaceae cf. *Miscanthus*				0				
Echinochloa				0				
Undet Millet whole+ fragments	3			0				
Undet Panicoid grass type 3				1				
Wild Poaceae Whole + fragments				0				
Polygonum persicaria type				0				
Polygonaceae				0				
Potamogeton				0				
Cf. Cyperaceae cotelydon				0				
Cf. *Scirpus* pericarp				0				
Cf. *Carex* type	1			0				
Cf. *Cyperus*				0				
Fruits								
Cratageus				0				
Sambucus				0				
Unidentified seeds	1			0			2	
Undet nutshell fragments				0				
Uncarbonized seeds	1	24		1	1		9	

Table C.1 Baodun Samples (Continued)	**210**	**208**	**199**
Litres	23	18	26
Wood (g)	0.1464	0.08	0.939
Cereals			
Oryza Whole		2	
Oryza frag.	8	2	1
Oryza Spikelets	1	8	45
Oryza Immature			
Oryza Embryo			
Oryza Whole + frag	8	4	1
Setaria italica Whole			
Setaria italica frag.	5		
Setaria italica whole+frag	5	0	0
Immature *Setaria*			
Total cereal	5	0	0
Coix			
c.f *Coix* Involucral bract fragments	1	2	
Upland Weeds			
Wild *Setaria* whole + frag			
Caryophyllaceae			
Digitaria whole+ frag	28		
Calamagrostis/Eragrostis/Aira			
Panicoid cf. *Andropogon* type 4			
cf. *Hackelochloa* frag.	22		2
cf. *Hackelocloa* whole			
cf. immature *Hackleocloa*			
Eleusine Indica			
Chenopodium			
Chenopodium frag.	2		
Solanum whole			3
Solanum Frag.	3		2
Galium			
Hyoscamus			
Xanthium			
cf. *Verbena*			
Perilla			
Lamiaceae cf. *Stachys*			
Pulses			
Vicia sp.		1	2
Vigna cf. *angularis*			1
Vigna cf. *radiate*			
Undet fabaceae			

Table C.1 Baodun Samples (Continued)	**210**	**208**	**199**
Wetland Weeds			
Fimbristylis whole silificified	2		
Fimbristylis frag silicified	11		7
Fimbristylis (small type)			
Cf. *Equisetum* plant sections			
Upland and Wetland Weeds			
Poaceae cf. *Miscanthus*			
Echinochloa	9		
Undet Millet whole+ fragments	11		
Undet Panicoid grass type 3	2		
Wild Poaceae Whole + fragments			
Polygonum persicaria type			
Polygonaceae			
Potamogeton			
Cf. Cyperaceae cotelydon			
Cf. *Scirpus* pericarp			
Cf. *Carex* type			
Cf. *Cyperus*			
Fruits			
Cratageus			
Sambucus			
Unidentified seeds	1		9
Undet nutshell fragments			
Uncarbonized seeds			1

Table C2 Zhonghai Samples

	117	**118**
Litres	43	20
Wood (2mm) Ct	1000+	200+
Wood (2mm) Wt (g.)	9.67	5.48
Cultivated Plants (2 species)		
Oryza Whole	39	10
Oryza Frag	278	142
Oryza Frag+whole	317	152
Oryza Spikelets Domesticated	1367	1016
Oryza Spikelets Immature	194	104
Oryza Spikelets Wild	781	122
Oryza Spikelets Undet	455	82
Oryza Spikelets Total	2797	1324
Carbonized *Oryza* husk		8
Oryza Embryo	156	29
Cf.*Oryza* fragments	56	29
Setaria italica Whole	3	6
Setaria italica Frag	3	
Immature *Setaria*		
Total cereal	379	187
Possibly cultivated plants		
Coix	4	
Coix utricle fragments ct.	240	
cf. *Vicia* whole	23	
cf. *Vicia* (half cotyledon)	294	1
cf. *Vigna*	1	
Type 1 cf. *Vigna* sp. (aguiculata or adzuki:short plumule)	2	
Undet Fabaceae type 2	5	
Vigna sp. fragments	2	3
Fruits/nuts		
Sambucus sp.	3	
Actidinia sp.		1
Prunus persica (fragments)	38	
Thick nutshell fragments cf. *Prunus persica*	55	
Endocarp type B (cf. *Carya*)	5	
cf. *Cratageus*		1
cf. *Cratageus* fragments	8	
Undet Nutshell fragments		8
Paddy Field and Wetland Weeds		
Poaceae cf. *Miscanthus*		2
Fimbristylis whole silificified	1	
Fimbristylis frag silicified	1	
Tiny cyperaceae (*Fimbristylis* other type)		1

Table C.2 Zhonghai (Continued)	**117**	**118**
Upland and Dryfield Weeds		
Wild *Setaria* whole	6	11
Wild *Setaria* frag	1	
Wild Poaceae Whole long seeded	6	
Digitaria	4	
cf. *Stipa*	6	
cf. *Stipa* fragments	22	
Eleusine indica	3	5
Caryophyllaceae		1
Cf. *Phytolacca*		2
Chenopodium		3
Amaranthus		11
Chenopodium frag.	12	
cf. *Xanthium* fragments	2	
Solanum cf. *xanthocarpum* (but too small)	12	
Solanaceae undet		1
Asteraceae cf. *Eupatorium* type	3	
Asteraceae	1	1
Caryophyllaceae	1	
Malva cf. *verticillata*	4	
Lamiaceae *Stachys* type	2	
Lamiaceae *Perilla* type	4	
Weeds common to both upland and paddy fields		
Echinochloa	3	
Polygonum type	1	1
Scirpus type	3	
Cyperus type		2
Undet Panicoid grass		1
Acalypha		1
Animal		
Snail shell		1
Crab shell fragments	26	
Bone fragments	64	34
Insect parts		2
Unidentified		
Undet 1 (check Liliaceae) or (Sterculiaceae)Melochia/ Pentapedes	42	
Undet 2 (maybe inside of sedge)	5	
Undet 4		18
Undet 26	2	
Undet 7	1	
Undet 8	1	
seed coat fragments	3	
Undet 11 Fungal sclerosa	4	

Table C.2 Zhonghai (Continued)	**117**	**118**
Undet 14	1	
Undet 15	1	
Undet 16 Fabaceae	1	
Undet 6	2	
Undet 21 Polygonaceae	1	
Undet 31		1
Undet Fabaceae/Solanaceae		1
Undet seed coat fragment		1
Branch	2	
Total seed count	4174	1624
Species count	43	23
Uncarbonized		
Sambucus	88	
Oxalis	6	3
Cyperaceae	4	4
Undet 1	3	2
Cyperaceae *perisicaria*	2	
Millet husk	11	25
Caryophyllaceae	1	4
Solanaceae		1
Undet		21
Eleusine indica		15
Fabaceae		3
Apiaceae		1
Flower and flower bud		2

Table C3 Guiyuanqiao Samples

	165	195	198	173	194+170	178
Liters	14	13	15	12	27	7
Wood (2mm) Ct	1	170	192	14	24	2
Wood (2mm+1mm) Wt	0	0.49		0.15	0.1	0
Bark wt.		0.04	0.07			
Bamboo			17			
Domesticates						
Oryza Whole			28	2	8	
Oryza Frag			192	3	39	5
Undet large fragments cf. *Oryza*			27			
Oryza Spikelet wild						
Oryza Spikelet domesticated			1			
Oryza spikelet undet						
Immature Rice						
Silicified rice husk						
Carbonized *Oryza* husk						
Oryza Embryo						
cf. *Avena* fragments			6			
Setaria cf. *italica* Whole	9	1	1	7	1	
Setaria cf. *italica* Frag					4	
Immature *Setaria*						
Panicum miliaceum whole	71	1	1	1	1	
cf. *Panicum m*. fragments	83					
Panicum long whole	3	1			3	
Panicum long frags	3					
cf. *Panicum ruderale* immature	2					
Panicum immature or wild	11					
cf. immature *Panicum*	3					
Total Grains	185	3	228	13	56	5
Weed flora						
immature millet					2	
small millet undet fragments	10					3
Wild *Setaria*			1	2		2
cf. Setaria frag	2					
cf. *Echinochloa*				3	1	
cf. *Digitaria* small whole				20	4	2
cf. *Digitaria* small fragments						3
Wild panicoid grass long				1	1	
Undet millet frags		1			7	
Wild Poaceae Whole						
Wild Poaceae Frag						
Undet Poaceae Whole						
Undet Poaceae Frag						
Eleusine indica						

Table C3 Guiyuanqiao (Continued)	**165**	**195**	**198**	**173**	**194+170**	**178**
Oxalis						
Grass culm			2			
cf. Lamiaceae						
cf. *Perilla*						
cf. *Perilla* pericarp fragments						
Caryophyllaceae						
Polygonaceae			1			
cf.*Cyperus*						
Chenopodium	15	3		5		3
Chenopodium perianth						
Chenopodium Frag	17			1		
Amaranthus						
Galium						
Solanaceae fragment				1		
Solanum			6			
cf. *Verbena*						
cf. Liliaceae triangular seed			4			1
Pulses						
Vicia whole			59		1	
cf. *Vicia* (half cotelydons)			99		4	
cf. *Vigna*			1			
cf. Fabaceae frag			1			
Fruits						
Vitis(wild)						
Uncarbonized						
Undet					3	
Red seed						
Wood		7			10	
cf. Ranunculaceae					3	
Leaf					1	
Polygonaceae					1	
Setaria husk						
Husks	1			3	10	2
Oxalis						
Galium						
Oryza husk						
Unidentified						
Undet fragments	294	13	100+	64	249	14
Undet embryo			1			
Undet 1	2					
Undet 2	2					
Undet 3 bean shaped					1	
Undet 5						1

Table C3 Guiyuanqiao (Continued)	**165**	**195**	**198**	**173**	**194+170**	**178**
Undet 7						
Undet 8						
Undet 9 (cf. *Chenopodium*)						
Undet 10 cf. Juncaeae				1		
Undet 11 (Large round hollow seed)						
Undet 12						
Undet 13 bean shaped hollow seed						
Undet 14						
Undet dicot fragment	2					
small nutshell					1	
Fruit flesh type						
Nutshell fragment large			1			
Nutshell with reticulate pattern					1	
Animal						
Ant		2			25	
Bone					1	
Crab					44	
Snail						

Table C3 Guiyuanqiao (Continued)	176	162	168	177	197	174+ 161	171	167
Liters	14	7	14	13	14	31	16	7
Wood (2mm) Ct	4	12	9	13	5	96	17	33
Wood (2mm+1mm) Wt	0.03	0.23	0.02	0.1	0.02		0.24	0.61
Bark wt.					1			
Bamboo								
Domesticates								
Oryza Whole	1					1	1	
Oryza Frag	1					9	1	
Undet large fragments cf. *Oryza*							1	
Oryza Spikelet wild								
Oryza Spikelet domesticated						1		
Oryza spikelet undet				1				
Immature Rice								
Silicified rice husk								
Carbonized *Oryza* husk								
Oryza Embryo								
cf. *Avena* fragments								
Setaria cf. *italica* Whole	1						3	
Setaria cf. *italica* Frag							3	
Immature *Setaria*								
Panicum miliaceum whole								
cf. *Panicum m*. fragments								
Panicum long whole						1		
Panicum long frags								
cf. *Panicum ruderale* immature								
Panicum like millet/ immature or wild								
cf. immature *Panicum*								
Total Grains	3	0	0	0	0	11	8	0
Weed flora								
Wild *Setaria*								
cf. *Echinochloa*						3		
cf. *Digitaria* small whole	2							
cf. *Digitaria* small fragments								
Wild panicoid grass long		1						
Undet millet frags			1	2	1	14		
Wild Poaceae Whole								
Wild Poaceae Frag								
Undet Poaceae Whole								
Undet Poaceae Frag								
Eleusine indica								
Oxalis								
Grass culm								
cf. Lamiaceae				1				

Table C3 Guiyuanqiao (Continued)	**176**	**162**	**168**	**177**	**197**	**174+ 161**	**171**	**167**
cf. *Perilla*						4		1
cf. *Perilla* pericarp fragments						20		
Caryophyllaceae								
Polygonaceae								
cf.*Cyperus*	1							
Chenopodium	1	1		2			1	1
Chenopodium perianth								
Chenopodium Frag		3						
Amaranthus	1							
Galium								
Solanaceae fragment								
Solanum								
cf. *Verbena*								
cf. Liliaceae triangular seed								
Pulses								
Vicia whole								
cf. *Vicia* (half cotelydons)						3		
cf. *Vigna*						1		
cf.Fabaceae frag				1				
Fruits								
Vitis(wild)								1
Uncarbonized								
Undet	1	8			1	2	13	
Red seed								
Wood					3			
cf. Ranunculaceae								
Leaf								
Polygonaceae								
Setaria husk								
Husks	4		1	2		2		
Oxalis								
Galium	1							
Oryza husk								
Pooid grass								
Unidentified								
Undet fragments	33	6	11	14	2	51	21	14
Undet embryo								
Undet 1								
Undet 2								
Undet 3 bean shaped								
Undet 4								
Undet 5								
Undet 6								

Table C3 Guiyuanqiao (Continued)	176	162	168	177	197	174+ 161	171	167
Undet 7				1				
Undet 8								
Undet 9 (cf. *Chenopodium*)								
Undet 10 cf. Juncaeae								
Undet 11 (Large round hollow seed)								
Undet 12								
Undet 13 bean shaped hollow seed								
Undet 14								
Undet dicot fragment								
small nutshell								
Fruit flesh type								
Nutshell fragment large		1		1				
Nutshell with reticulate pattern				2				
Animal								
Ant								100
Bone								
Crab		67						
Snail								

Table C3 Guiyuanqiao (Continued)	**169**	**175**	**192**	**191**	**172**	**164**	**163**	**196**
Litres	14	15	6	6	14	15	11.5	6
Wood (2mm) Ct	82	37	309	287	46	5	1	7
Wood (2mm+1mm) Wt		0.52	0.92	0.98	0.53	0.06	0	0.03
Bark wt.							2	
Bamboo					4			
Domesticates								
Oryza Whole	1		1	1				
Oryza Frag	9			10				
Undet large fragments cf. *Oryza*								
Oryza Spikelet wild	1							
Oryza Spikelet domesticated				1			1	
Oryza spikelet undet								
Immature Rice								
Silicified rice husk								
Carbonized *Oryza* husk						1		
Oryza Embryo								
cf. *Avena* fragments								
Setaria cf. *italica* Whole			1	4	1			
Setaria cf. *italica* Frag			1	2	2			
Immature *Setaria*								
Panicum miliaceum whole								
cf. *Panicum m*. fragments								
Panicum long whole								
Panicum long frags								
cf. *Panicum ruderale* immature								
Panicum like millet/ immature or wild			2					
cf. immature *Panicum*								
Total Grains	10	0	5	17	3	0	0	0
Weed flora								
immature millet								
small millet undet fragments								
Wild *Setaria*								
cf. Setaria frag								
cf. *Echinochloa*								
cf. *Digitaria* small whole								
cf. *Digitaria* small fragments								
Wild panicoid grass long								
Undet millet frags			3	2		1		
Wild Poaceae Whole								
Undet Poaceae Frag								
Eleusine indica	1						1	
Oxalis						1		
Grass culm	1							
cf. Lamiaceae			1					

Table C3 Guiyuanqiao (Continued)	**169**	**175**	**192**	**191**	**172**	**164**	**163**	**196**
cf. *Perilla*								
cf. *Perilla* pericarp fragments	4			1				
Caryophyllaceae								
Polygonaceae								
cf.*Cyperus*								
Chenopodium				19				1
Chenopodium perianth		1						
Chenopodium Frag								
Amaranthus							4	
Galium								
Solanaceae fragment	1							
Solanum								
cf. *Verbena*								
cf. Liliaceae triangular seed								
Pulses								
Vicia whole								
cf. *Vicia* (half cotelydons)			2					
cf. *Vigna*								
cf.Fabaceae frag								
Fruits								
Vitis (wild)				1				
Uncarbonized								
Undet				1		13	33	
Red seed			63					
Wood								
cf. Ranunculaceae								2
Leaf		1						
Polygonaceae								
Setaria husk			1					36
Husks		2			3			
Oxalis								1
Galium								1
Oryza husk	1							1
Pooid grass			2	2				153
Unidentified								
Undet fragments	21	5	8	33	9	2	1	
Undet embryo								
Undet 1								
Undet 2								
Undet 3 bean shaped								
Undet 4	1							
Undet 5								
Undet 6						1		

Table C3 Guiyuanqiao (Continued)	**169**	**175**	**192**	**191**	**172**	**164**	**163**	**196**
Undet 7								
Undet 8							1	
Undet 9 (cf. *Chenopodium*)							2	
Undet 10 cf. Juncaeae								
Undet 11 (Large round hollow seed)			1					
Undet 12								1
Undet 13 bean shaped hollow seed				1				
Undet 14	2							
Undet dicot fragment								
small nutshell								
Fruit flesh type								
Nutshell fragment large								
Nutshell with reticulate pattern								
Animal								
Ant								
Bone							6	
Crab	11							
Snail								

Table C3 Guiyuanqiao (Continued)	**193**
Litres	15
Wood (2mm) Ct	151
Wood (2mm+1mm) Wt	0.61
Bark wt.	
Bamboo	
Domesticates	
Oryza Whole	
Oryza Frag	
Undet large fragments cf. *Oryza*	
Oryza Spikelet wild	
Oryza Spikelet domesticated	
Oryza spikelet undet	
Immature Rice	
Silicified rice husk	
Carbonized *Oryza* husk	
Oryza Embryo	
cf. *Avena* fragments	
Setaria cf. *italica* Whole	
Setaria cf. *italica* Frag	
Immature *Setaria*	
Panicum miliaceum whole	
cf. *Panicum m*. fragments	
Panicum long whole	1
Panicum long frags	
cf. *Panicum ruderale* immature	
Panicum like millet/ immature or wild	
cf. immature *Panicum*	
Total Grains	1
Weed flora	
immature millet	
small millet undet fragments	
Wild *Setaria*	
cf. Setaria frag	
cf. *Echinochloa*	1
cf. *Digitaria* small whole	
cf. *Digitaria* small fragments	
Wild panicoid grass long	
Undet millet frags	2
Wild Poaceae Whole	
Wild Poaceae Frag	
Undet Poaceae Whole	
Undet Poaceae Frag	

Table C3 Guiyuanqiao (Continued)	**193**
Eleusine indica	
Oxalis	
Grass culm	
cf. Lamiaceae	
cf. *Perilla*	
cf. *Perilla* pericarp fragments	
Caryophyllaceae	
Polygonaceae	
cf.*Cyperus*	
Chenopodium	
Chenopodium perianth	
Chenopodium Frag	
Amaranthus	
Galium	
Solanaceae fragment	
Solanum	
cf. *Verbena*	
cf. Liliaceae triangular seed	
Pulses	
Vicia whole	
cf. *Vicia* (half cotelydons)	
cf. *Vigna*	
cf.Fabaceae frag	
Fruits	
Vitis (wild)	
Uncarbonized	
Undet	1
Red seed	
Wood	
cf. Ranunculaceae	
Leaf	
Polygonaceae	
Setaria husk	1
Husks	
Oxalis	
Galium	
Oryza husk	1
Pooid grass	
Unidentified	
Undet fragments	
Undet embryo	
Undet 1	
Undet 2	

Table C3 Guiyuanqiao (Continued)	**193**
Undet 7	
Undet 8	
Undet 9 (cf. *Chenopodium*)	
Undet 10 cf. Juncaeae	
Undet 11 (Large round hollow seed)	
Undet 12	
Undet 13 bean shaped hollow seed	
Undet 14	
Undet dicot fragment	
small nutshell	
Fruit flesh type	
Nutshell fragment large	
Nutshell with reticulate pattern	
Animal	
Ant	
Bone	
Crab	
Snail	

Table C4 Bolocun Samples 1

	63	69+66	62	64	72
Litres	14	36.5	7	15	16
Wood (2mm) Ct					
Wood (2mm) Wt (g.)					
Bark	2				
Cultivated Plants (2 species)					
Oryza Whole	36	52	53	4	47
Oryza Frag	0	123	244	74	301
Oryza Whole+Frag	36	175	297	78	348
Oryza Spikelets Domesticated	210	614	1807	257	502
Oryza Spikelets Immature	43	155	538	34	197
Oryza Spikelets Wild	43	153	506	74	123
Oryza Spikelets Undet	53	150	255	70	76
Oryza Spikelets Total	349	1072	3106	435	898
Carbonized *Oryza* husk		2			1
Oryza Embryo	9	60	83	22	59
Cf.*Oryza* fragments	107			6	16
Setaria italica Whole	16	324			1
Setaria italica Frag	10	41		2	
Immature millet	2	348			
*Setaria italica T*otal	28	713	0	2	1
cf.Averna/secale fragment					
Millet embryo		10			
Undet millet fragments		219			
Total grains	64	888	297	80	349
Possibly cultivated plants					
Coix utricle fragments ct.		1			
cf. *Vicia* whole	1	1			2
cf. *Vicia* (half cotelydon)	0		2		6
Total *Vicia*	1	1	2	0	8
Vigna undet		1			1
Vigna short plumule (cf. *V.angularis*)		1			
Vigna long plumule	5		1		
Vigna whole undet		4			
Vigna sp. fragments	5	4			
Total *Vigna*	10	10	1	0	1
cf. *Glycine max*		2			
Fruits/nuts					
Sambucus sp.		1			
Actidinia sp.			2	1	
Prunus persica (fragments)					
Thick nutshell frament cf. *Prunus persica*					
Endocarp type B (*Carya*)	7	9			

Table C4 Bolocun Sample (Continued)	**63**	**69+66**	**62**	**64**	**72**
Undet Nutshell fragments		16	1		
tiny pericarp		1			
Upland and Dryfield Weeds					
Wild *Setaria* whole	2	14			
Wild *Setaria* frag	1				5
Wild *Setaria* total	3	14	0	0	5
Undet Panicoid grass fragment					14
Wild Poaceae Whole long seeded			2		
Eleusine indica					1
Chenopodium			2		
Solanum cf. *xanthocarpum*					
Solanaceae undet	1				
Galium					
Malva					
Lamiaceae *Stachys* type				1	1
Perilla			3	1	
Lamiaceae *Perilla* type(fragment)	1	4			
Verbena sp.	3				
Weeds common to both upland and paddy fields					
Echinochloa	1	166	19		5
Polygonaceae			2	6	1
Scirpus type					
Cyperaceae			3		
Undet Panicoid grass					
Acalypha	0	0	0	0	0
Animal					
Bone fragments	1	15	73	21	22
Insect parts					
Leaf					
Unidentified					
Undet 1 Round flat seed	1				
Undet 2	1				
Undet 3 (cf chenopod			1		
Undet cf. Liliaceae triangular seed		1	1		
Undet 4					
Cf. *Phyllanthus* pod					
cf. *Verbena* like pod					
pod with reticulated surface					
Undet 5					
Under pericarp					
Undet 6					
Pericarp with lines					
Undet 7					

Table C4 Bolocun Sample (Continued)	**70**	**68**	**65**	**71**
Litres	21	27.5	13	21
Wood (2mm) Ct				
Wood (2mm) Wt (g.)				
Cultivated Plants (2 species)				
Oryza Whole	32	44	306	42
Oryza Frag	438	240	467	76
Oryza Whole+Frag	470	284	773	118
Oryza Spikelets Domesticated	98	262	301	340
Oryza Spikelets Immature	82	63	47	84
Oryza Spikelets Wild	57	116	86	94
Oryza Spikelets Undet	78	92	21	35
Oryza Spikelets Total	315	533	455	553
Carbonized *Oryza* husk				
Oryza Embryo	20	79	190	29
Cf.*Oryza* fragments		14		
Setaria italica Whole	19		12	8
Setaria italica Frag	23	5	7	
Immature millet	12	1	9	
Setaria italica Total	54	6	28	8
cf.*Averna/secale* fragment		1		
Millet embryo			2	
Undet millet fragments		3		9
Grass rachis cf.triticaecae			1	
Total grains	524	291	801	126
Possibly cultivated plants				
Coix utricle fragments ct.				
cf. *Vicia* whole				18
cf. *Vicia* (half cotelydon)	2	1	5	10
Total *Vicia*	2	1	5	28
Vigna undet		4		1
Vigna short plumule (cf. *V.angularis*)			1	
Vigna long plumule	2			
Vigna whole undet	2	2	2	
Vigna sp. fragments			1	
Total *Vigna*	4	6	4	1
cf. *Glycine max*			1	
Undet Fabaceae		3		
Fruits/nuts				
Sambucus sp.				
Actidinia sp.				
Prunus persica (fragments)			1	
Thick nutshell frags cf. *Prunus persica*				1
Endocarp type B (*Carya*)				

Table C4 Bolocun Sample (Continued)	**70**	**68**	**65**	**71**
Undet Nutshell fragments	22			3
Tiny pericarp				
Upland and Dryfield Weeds				
Wild *Setaria* whole				
Wild *Setaria* frag			2	
Wild *Setaria* total	0	0	2	0
Undet Panicoid grass fragment	18			
Wild Poaceae Whole long seeded			1	
Eleusine indica				
Chenopodium		6		2
Solanum cf. *xanthocarpum*		2		
Solanaceae undet				
Galium			1	1
Malva		1		
Lamiaceae *Stachys* type	6	18		4
Perilla		4		
Lamiaceae *Perilla* type(fragment)				
Verbena sp.	1		1	1
Weeds common to both upland and paddy fields				
Echinochloa	6	8	18	
Polygonaceae				
Scirpus type				
Cyperaceae				
Undet Panicoid grass				
Acalypha	0	0	0	0
Animal				
Bone fragments	8	15		19
Insect parts	6			2
Leaf		1		
Unidentified				
Undet 1 Round flat seed				
Undet 2				
Undet 3 (cf chenopod)				
Undet cf. Liliaceae triangular seed	1			
Undet 4	1			
cf. *Phyllanthus* pod	1			
cf. *Verbena* like pod	1	1		
Pod with reticulated surface	1			
Undet 5		1		
Under pericarp		1		
Undet 6				
Pericarp with lines			1	
Undet 7			1	

Table C4 Bolocun Sample (Continued)	**73**	**74**
Litres	21.5	8.5
Wood (2mm) Ct		
Wood (2mm) Wt (g.)		
Bark		
Cultivated Plants (2 species)		
Oryza Whole	202	0
Oryza Frag	33	0
Oryza Whole+Frag	235	0
Oryza Spikelets Domesticated	148	
Oryza Spikelets Immature	17	
Oryza Spikelets Wild	26	
Oryza Spikelets Undet	2	1
Oryza Spikelets Total	193	1
Carbonized *Oryza* husk		
Oryza Embryo	79	0
Cf.*Oryza* fragments		
Setaria italica Whole		
Setaria italica Frag	5	
Immature millet	2	
*Setaria italica T*otal	7	0
cf.Averna/secale fragment		
Millet embryo		
Undet millet fragments		
grass rachis cf.triticaecae		
cf.triticacee fragment	1	
Total grains	242	0
Possibly cultivated plants		
Coix utricle fragments ct.		
cf. *Vicia* whole		
cf. *Vicia* (half cotelydon)		
Total *Vicia*	0	0
Vigna undet		
Vigna short plumule (cf. *V.angularis*)		
Vigna long plumule		
Vigna whole undet	2	
Vigna sp. fragments	5	
Total *Vigna*	7	
cf. *Glycine max*		
Fruits/nuts		
Sambucus sp.	1	0
Actidinia sp.	1	0
Prunus persica (fragments)		0
Thick nutshell frament cf. *Prunus persica*		0
Endocarp type B (*Carya*)		0

Table C4 Bolocun Sample (Continued)	**73**	**74**
Undet Nutshell fragments		0
Tiny pericarp		0
Upland and Dryfield Weeds		
Wild *Setaria* whole		
Wild *Setaria* frag		
Wild *Setaria* total	0	0
Lamiaceae *Perilla* type(fragment)		
Verbena sp.	1	
Weeds common to both upland and paddy fields		
Echinochloa	1	
Polygonaceae		
Scirpus type		
Cyperaceae		
Undet Panicoid grass		
Acalypha	0	0
Animal		
Bone fragments	8	
Insect parts	1	

Table C5 Sanhehuayuan Samples

	76+84	**78**	**82**	**85**	**83**	**80**
Litres	41.5	16.5	14	16	15	33.5
Wood (2mm) Ct	491	337	30	21	117	147
Wood (2mm) Wt						
Cultivated Plants						
Oryza Whole	9	1	3		6	8
Oryza Frag	90	12	9	8	36	64
Oryza Whole+Frag	99	13	12	8	42	72
Oryza spikelet domesticated	1		1	1		
Oryza spikelet undet	0	1		1		
Oryza spikelet wild						
Oryza Spikelets total						
Oryza Embryo	4			1	2	
Oryza husk fragment						1
Setaria italica Whole	2	11			2	3
Setaria italica Frag		8	1	3	7	9
Immature *Setaria*	1					8
Setaria italica Total	3	19	1	3	9	20
Panicum miliaceum	0			1		1
Panicum immature	0					
cf. *Panicum miliceum* Frag	0				1	
Panicum miliaceum Total	0	0	0	1	1	1
Cereals Total	102	32	13	12	52	93
Pulses						
Vicia whole		1				
Vicia fragment	1	14				
Vicia total	1	15	0	0	0	0
Upland and Dryland weeds						
Wild *Setaria* whole	1					3
Wild *Setaria* frag	1		1			7
Wild *Setaria* total	2	0	1	0	0	10
cf. *Panicum* wild	1					
cf. *Digitaria*			8	8	24	18
Eleusine indica		1				
Undet Millet frag	3			6	5	1
Caryophyllaceae		1				
Amaranthaceae Frag	5			1		2
Chenopodium Whole	0				1	1
Chenopodium Frag	0		1	2	1	
Solanaceae					2	1
Lamiaceae type 1		7			1	4
Xanthium pericarp						1

Table C5 Sanhehuayuan (Continued)	76+84	78	82	85	83	80
Weeds common to Upland and Wetland						
Echinochloa	1		5			
Large Poaceae Frag			1			
Undet pooid grass fragment				2	11	2
Undet Panicoid grass (long embryo)		1				10
Undet Poaceae Whole			1			
Undet Poaceae Frag	3				17	
Polygonum		1			1	
Cyperaceae					1	2
cf. grass culm			3			3
Grass rachis						1
Wetland weeds						
Commenaliaceae					1	
cf. *Potamogeton*						8
Fruits						
cf.*Sambucus*	0	1	0	0	0	0
Prunus persica type fragment	2					
Unidentified						
cf. Scrophuraliaceae	2			1	16	73
cf. Scrophuraliaceae	0				1	76
Undet thick smooth nutshell frag	8				1	
Undet nutshell fragment	9	11				
Undet stem fragment				1		
Undet 6		3				
Undet 18						1
Undet 40 Commenlinaceae		10				
Undet 41		2				1
Undet 42 cf. Almaceae celtis		4				
Undet 43		4				
Undet 44 cf. *Myrica*		2				
Undet 45		1				
Undet 46			1			
Undet 47					1	
Undet 48					1	
Undet 50						1
Resin	64	5	5		3	16
Undet fragments	308	143	86	45	219	319

Table C5 Sanhehuayuan (Continued)	**76+84**	**78**	**82**	**85**	**83**	**80**
Uncarbonized		4				
Millet husk		5				
Caryophyllaceae		1				
Zhenaria		15				
Solanaceae		1				5
Sambucus		1				
Oxalis		2				
Cyperus		4				
Amaranthus						
Animal						
Insect		12				
Bone		5	2		29	8

Table C5 Sanhehuayuan (Continued)	**79**
Litres	15
Wood (2mm) Ct	59
Wood (2mm) Wt	
Cultivated Plants	
Oryza Whole	3
Oryza Frag	18
Oryza Whole+Frag	21
Oryza spikelet domesticated	7
Oryza spikelet undet	
Oryza spikelet wild	1
Oryza Spikelets total	
Oryza Embryo	1
Oryza husk fragment	
Setaria italica Whole	4
Setaria italica Frag	1
Immature *Setaria*	3
Setaria italica Total	8
Panicum miliaceum	
Panicum immature	
cf. *Panicum miliceum* Frag	2
Panicum miliaceum Total	2
Cereals Total	31
Pulses	
Vicia whole	
Vicia fragment	
Vicia total	0
Upland and Dryland weeds	
Wild *Setaria* whole	
Wild *Setaria* frag	
Wild *Setaria* total	0
cf. *Panicum* wild	
cf. *Digitaria*	5
Eleusine indica	
Caryophyllaceae	
Amaranthaceae Frag	1
Chenopodium Whole	
Chenopodium Frag	
Solanaceae	
Lamiaceae type 1	
Lamiaceae type 2 *Stachys*	0
Xanthium pericarp	

Table C5 Sanhehuayuan (Continued)	**79**
Weeds common to Upland and Wetland	
Echinochloa	1
Wild Poaceae Whole	
Large Poaceae Frag	
Undet pooid grass fragment	
Undet Panicoid grass (long embryo)	
Undet Poaceae Whole	2
Undet Poaceae Frag	
Polygonum	
Cyperaceae	
cf.grass culm	
grass rachis	
Wetland weeds	
Commenaliaceae	
cf. *Potamogeton*	
Fruits	
cf. *Sambucus*	0
Prunus persica type fragment	
Unidentified	
cf. Scrophuraliaceae	13
cf. Scrophuraliaceae frags.	10
Undet fragments	45
Uncarbonized	
Millet husk	
Caryophyllaceae	
Zhenaria	
Solanaceae	
Sambucus	
Oxalis	
Cyperus	
Amaranthus	
Animal	
Insect	
Bone	

Table C6 Qingchengjian samples

	86	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**
Litres	1	1	9	9	5.5	9	10	4	4.5
Wood Charcoal (g)	0.014	0.33	0.396	0.083	0.11	1.534	0.408	0.963	0.093
Cereals									
Oryza whole	6	2	15	31	3	32	35	17	20
Oryza frag	10	1	25	100	4	67	32	51	34
Oryza embryo	8	8	8	11		2	2	9	7
Oryza spikelets	9	1	24	61		131	31	229	35
Setaria italica		1	1	19		4	1	14	
Hordeum vulgare			2						
Total Grains	16	4	43	150	7	103	68	82	54
Pulses									
cf *Glycine max*									
Vigna sp.whole			1				8		
Vigna sp. frag				1			31	1	
Vicia sp.whole				1			1		
Vicia sp.frag				2					4
Upland Weeds									
Chenopodium				1			5	2	1
cf. *Perilla*			1					3	
Eleusine indica									
Wild *Setaria*				2				4	2
Wild *Panicum*									
Verbena sp.							1		
Upland and Wetland Weeds									
Poaceae									
Echinocloa sp			1	6				4	2
Immature millet									
Pooideae grass (long)				1				3	
Large Poaceae	0								
Small Poaceae	0								
Cyperaceae									
Polygonaceae							1		
Wetland Weeds									
Fimbrystylis sp.									
Fruit									
Prunus persica frag.				2		1	1	2	
Undet seeds	1	1	1	2			1		

Table C6 Qingchengjian (Continued)	**SX95**	**SX119**	**SX120**	**SX121**	**SX122**
Litres	4.5	9	15	16	13
Wood Charcoal (g)	0.644	0.53	1.542	0.393	
Cereals					
Oryza whole	39	24	72	12	13
Oryza frag	33	32	184	19	9
Oryza embryo	3	7	21	4	0
Oryza spikelets	3	19	64	25	11
Setaria italica	2	1	5	1	2
Hordeum vulgare					1
Total Grains	74	57	261	32	25
Pulses					
cf Glycine max					1
Vigna sp.whole					1
Vigna sp. frag			4		
Vigna sp. total			4		1
Vicia sp.whole			1	1	
Vicia sp.frag			4	2	
Vicia sp. total			5	3	
Upland Weeds					
Chenopodium			1	2	1
cf. *Perilla*			5		1
Eleusine indica					
Wild *Setaria*					
Wild *Panicum*			1		
Verbena sp.					
Upland and Wetland Weeds					
Poaceae					
Echinocloa sp	1	6		3	
Immature millet	3				
Pooideae grass (long)		2		1	
Large Poaceae	1		4		
Small Poaceae		1	1	1	2
Cyperaceae			1	1	
Polygonaceae			1		
Wetland Weeds					
Fimbrystylis sp.				1	
Fruit					
Prunus persica frag.				7	
Undet seeds	1				

Table C7 Hongsecun Samples

	144	**145**
Litres	10	14
Wood Charcoal (g)	0.652	1.423
Cereals		
Oryza whole	10	19
Oryza frag	14	31
Oryza embryo	18	10
Oryza spikelet		8
Oryza Total	24	50
Upland Weeds		
Wild *Setaria*		1
Chenopodium	2	
Eleusine indica	2	

Table C8 Huayulang Samples

	123	**124**	**146**
Litres	123	11	13
Wood Charcoal (g)	13.156	7.041	4.846
Cereal			
Oryza whole	31	26	11
Oryza frag		50	17
Oryza embryo		21	6
Oryza spikelet		535	249
Oryza total	31	76	28
Setaria italica	1	1	1
Fabaceae			
*Vigna sp.*frag		1	
Vicia whole		1	
Vicia frag		3	
Upland weeds			
cf. *Perilla*	1		
Cyperaceae		1	
Solanaceae		1	

Table C9 Languang Yongjinwan

	136	**137**	**138**	**139**	**140**
Litres	17	16	23	24.5	21.5
Wood Charcoal (g)	2.298	0.273	0.43	2.245	0.214
Cereal					
Oryza whole	48	7	14	7	2
Oryza frag	22		12	4	
Oryza embryo					
Oryza spikelet					
Oryza total	70	7	26	11	2
Setaria italica	2	4	1	2	
Pulses					
Vigna sp.frag	4				
Vicia sp.whole	3		1		
Vicia sp. frag	17				
Upland Weeds					
cf. *Phyllanthus*			1		
Wild *Setaria*					1
Pooideae grass (long)	1				
Upland and Wetland Weeds					
Polygonum	11				
Echinocloa sp.			2		
Fruit					
Prunus persica frag	2				
Undet seeds	2				

Table C10 Qibazu samples

	142	**143**
Litres	13	16
Wood Charcoal (g)	0.452	0.217
Cereals		
Oryza whole	1	4
Oryza frag	7	5
Oryza embryo		2
	8	9
Setaria italica	3	1
Hordeum vulgare		1
Fruit		
Prunus persica	4	
Upland weeds		
cf *Perilla*		1
Chenopodium	1	4
Eleusine indica		1

Table C11 Zhuxin Kejiyuan

	125	**126**	**127**
Litres	23	21	42
Wood Charcoal	2.673	0.822	1.285
Cereals			
Oryza whole	78	8	12
Oryza frag			15
Oryza embryo	2	1	
Oryza total	78	8	27
Setaria italica		2	
Pulses			
*Vicia sp.*whole			2
*Vicia sp.*frag			7
Upland weeds			
cf .*Perilla*			1
Upland and lowland weeds			
Echinocloa sp.	3	3	
Cyperaceae	1		1
Immature millet			1

Table C12 Yangguangdidai

	141
Litres	47
Wood Charcoal (g)	10.413
Cereal	
Oryza whole	205
Oryza frag	243
Oryza embryo	4
Oryza spikelet	68
Oryza total	448
Setaria italica	194
Pulses	
Vigna sp.whole	1
Vigna sp. frag	1
Fruit	
Prunus persica	2
Upland Weeds	
cf. *Perilla*	1
Wild *Setaria*	14
Wild *Panicum*	1

Table C13 Songjiaheba

	2,4	**6,7,8**	**3,5**	**1,9,10**
	11	31	13	53
Bambusoide count		2		
Oryza Whole		1	1	6
Oryza Fragment	4	15	32	32
Oryza Spikelets Domesticated type	1	2	1	4
Oryza Spikelet Wild type			1	
Oryza Spikelets unidentifiable				1
Oryza total	5	18	35	42
Setaria italica Whole		2	1	
Setaria italica Fragment		1	1	
Wild *Setaria*		4	1	
Immature *Setaria*			1	
Undet Panicoid fragments			1	
cf. *Echinochloa* fragments			1	
Wild Poaceae Whole		1	1	
Wild Poaceae fragment				1
Amaranthaceae fragment			1	
cf. *Panicum* sp.				1
cf. *Galium* sp.		1		
Vitis sp.	1			
Undet Nutshell				1
Amygdalus (Prunus)persica		4		
Vicia sp.			1	
Undet Fabaceae oblong		1		
	2	8	7	5
Bone fragments		3		
Uncarbonized				
Oryza husk				14
Cyperaceae		5	1	1
Cyperaceae scirpus type .				5
Caryophyllaceae		1		
Poaceae	3			
Poaceae husk				8
Setaria Lemma				3

Table C14 Shiweigan samples

Sample Number	**11**	**12**
Cereals		
Oryza		
Oryza spikelet	1	
c.f Panicum(?)	1	1
undet millet	1	
Weeds		
Scirpus	1	1
Oxalis	16	
Eleusine Indica	5	
Unidentifiable	4	6
Uncarbonized		
Undet	21	
Caryophllaceae	21	
Chenopodiaceae	5	
Umbelliferae	1	
Polygonaceae	1	

Table C15 Tibet Samples

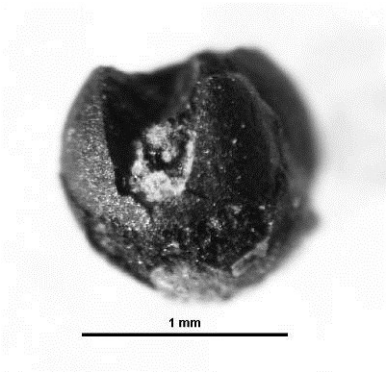
	Changdu Karuo (Unit 7)						Kyung Lung Silver Castle (Desiccated)	
Sample	**H2**	**H4**	**L3**	**K1**	**H1**	**F1**	**Structure 66**	**KLB 区北端**
Papery bark >2mm wt. *								4.37
Wood >2mm wt. *								13.03
Wood >2mm ct.	239	202	298	1000+	411	597	1000+	36
Wood >2mm wt.	1.9	0.98	2.3	19.8	3.24	3.98	21.61	0.12
Berberis Thorn *								x†
Spine *								x†
Juniper Twigs *								x†
Cerealia frags							14	
Cerealia embryo							2	
Hordeum vulgare							14	1
H. vulgare frag							15	
H. vulgare (naked)								
H. vulgare (naked) frag								
H. vulgare (hulled)								
H. vulgare (hulled) frag								
H. vulgare rachis *								44
H. vulgare rachis								2
Triticum aestivum							2	
cf. *Hordeum* (wild)							1	
Setaria italica	15	16	2		8	3		
S. italica frags		14	3		3			
Setaria italica embryo	1	3						
Setaria immature	8				3	2		
cf. *Setaria* frags		3				1		
S. italica palea-lemma								5
Panicum miliaceum	1	3				2		
P. miliaceum frags	1	4						
Fagopyrum sp.							2	
Fagopyrum sp. frag.							1	
Poaceae	4	2			1			1
Pooid	2						20	
Pooid *								1
Panicoid	7	32			2	4	5	1
Echinocloa					2			
Setaria (wild)	6	9	1			1		
Cheno-am	9	2	1					1
Chenopodium large	9	7	1			3	11	2
Chenopodium small	4				2	2	17	4

Table C14 Tibet Samples (Continued)	**H2**	**H4**	**L3**	**K1**	**H1**	**F1**	**Structure 66**	**KLB 区北端**
Chenopodium perisperm only						4		
Cyperaceae type A							54	26
Cyperaceae type B							13	2
Cyperaceae type C							3	
Cyperaceae type D							11	
Cyperaceae type E							24	
cf. *Capsella*							1	8
Polygonum			1				4	10
Polygonum/ *Fagopyrum*							4	
cf. *Rumex*	2							
Pinus seed coat*								1
Rubus	1					1		
cf. *Rubus*			1					
Fragaria/Potentilla	5	4	1		6	3	19	8
Ajuga	1							
Alhagi							16	
cf. *Fabaceae* pod							1	
Unidentified	2	3			5			1
Unidentifiable frags	45					32	166	
Grass culm		2						9
Bone >1.4mm *	53	2	3			23	9	9
Snail shell >1.4mm *	11	12	4	1	4	5	1	
Fungal >1.4mm	1							
Insect >1.4mm		1						
Resin >1.4mm		22	13		32	59	10	
Dung pellets wt.							2.67	

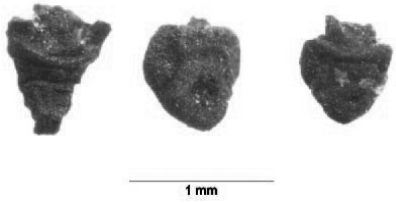
Appendix D – Images of Archaeological Seeds
The following pages present macrophotographic images the archaeological seeds examined for this dissertation. All photographs were taken an Olympus camera and software. Samples from Guiyuanqiao were photographed at the laboratory at Peking University.

1.) Domesticates (cereals)

Rice (*Oryza sativa*) #58



Foxtail millet (*Setaria italica*) #55



Rice (*Oryza sativa*) spikelets #52
(from left to right:
immature, domesticated and wild)

Broomcorn Millet (*Panicum miliaceum*)
#165

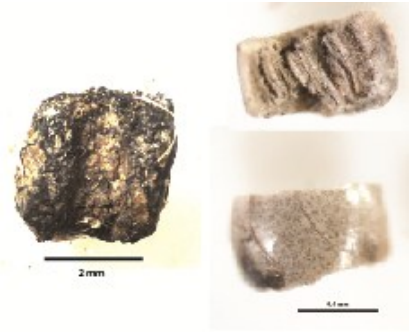
Panicum ruderale #165

Barley (*Hordeum vulgare*) #88

Barley (*Hordeum vulgare*) #225

Wheat (*Triticum aestivum*) #225

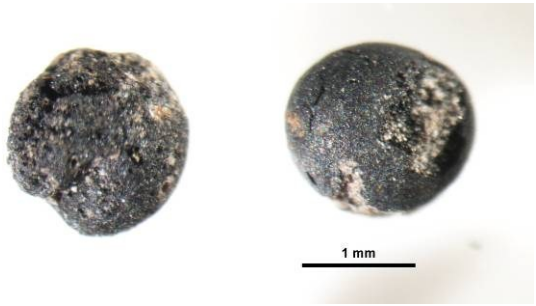
Buckwheat (*Fagopyrum* sp.) #225



Job's tears (*Coix* sp.) #217

2.) Pulses

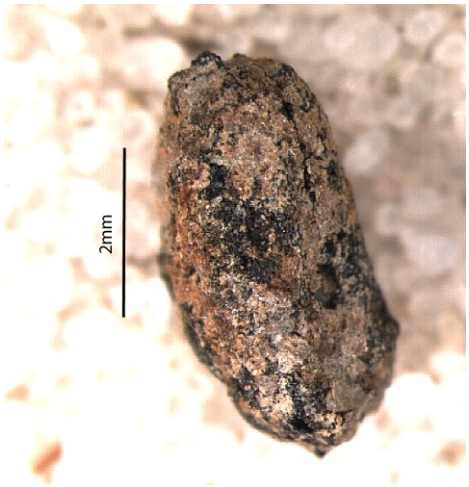
Vicia sp. (half cotyledon) #54



Vicia sp. (whole) #54

Vigna cf. *angularis* #203

Vigna cf. #55



Soybean (*Glycine max*) #122

Vigna (undet) #92

3.) Fruits

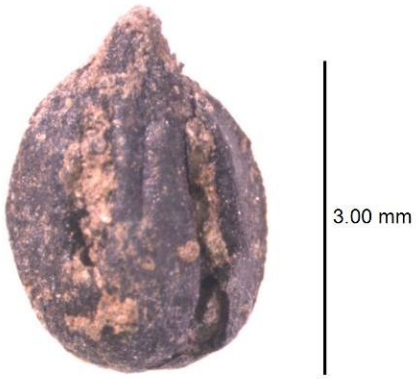
Peach (*Prunus persica*) endocarp #119

Kiwi Fruit (*Actidinia* sp.) #118

Elderberry (*Sambucus* sp.) #117

Hawthorn (*Cratageus* sp.) #214

Wild grape (*Vitis* sp.) #191



Wild grape (*Vitis* sp.) #191

Rubus sp. #150

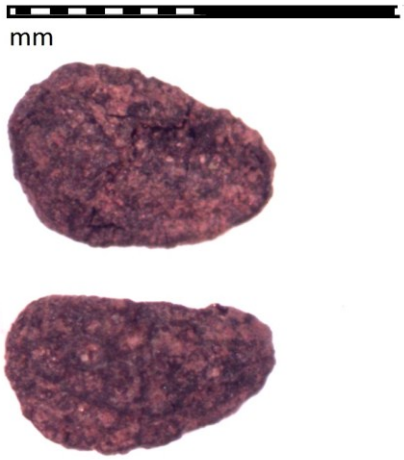
Fragaria sp./ *Potentilla* sp. #150

Pine nut (*Pinus* sp.) #224

Fragaria sp./ *Potentilla* sp.#224

4.) Weeds:

cf. *Capsella* #224



Ajuga sp. #150

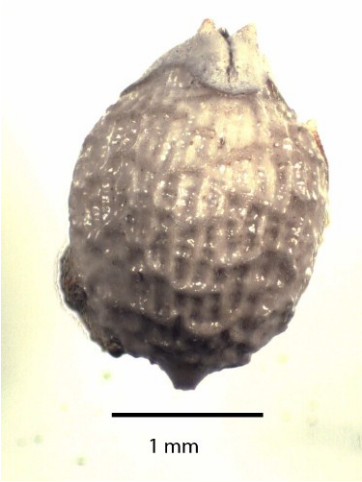
Chenopodium sp. #224

Cyperaceae type A #224

Polygonum sp. #224

Equisetum sp. stem sections

Potamogeton sp. #221



Hacklelocloa sp. #185

Fimbrystylis sp. #204

Lamiaceae cf. *Stachys* #203

cf. *Perilla* #204

cf. *Acalphya* sp. #118

cf. *Scrophulariaceae* #80

Phytolacca sp. #119

Malva sp. # 117

Polygonum sp. #118

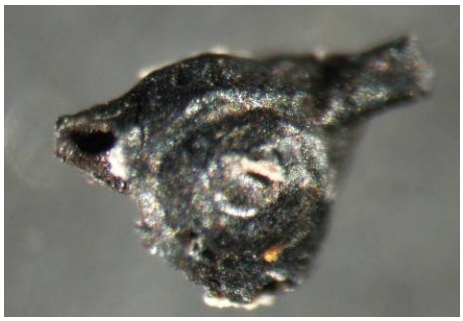
Solanum sp. #117

Xanthium sp. fragment #117

5.) Unidentified seeds:

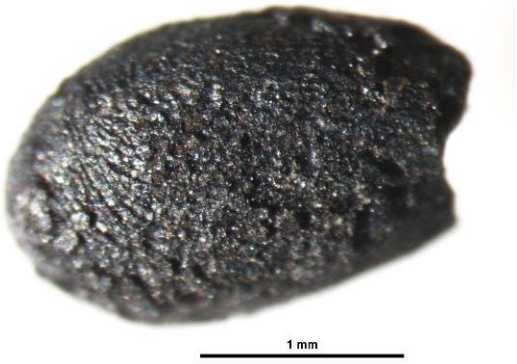
Undet 1 (possibly Sterculiaceae family) cf. *Melochia* sp.

Undet 2

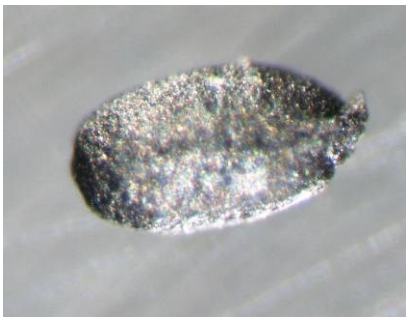


Undet #3

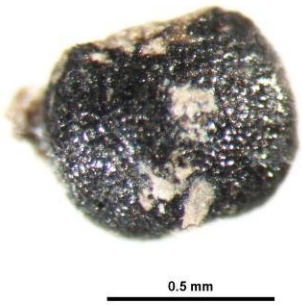
Undet #5



Undet #8



Undet #9



Undet #10

Undet #12

Undet 14 #

Undet 15 #

Undet 16

Undet 18

Undet 20

Undet 21

Undet #22

Undet #23

Undet 27

Undet 28

Undet 28

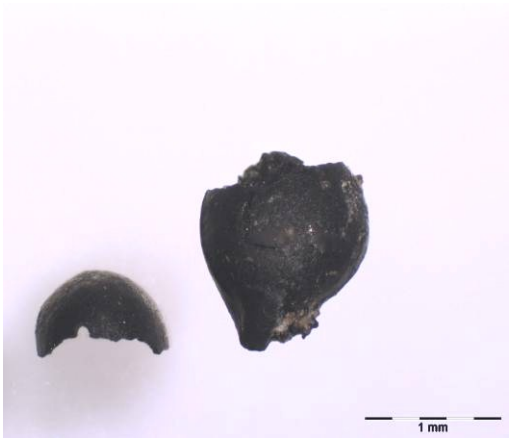
Undet 29

Undet 31

Undet 34

Undet 37

Undet 40

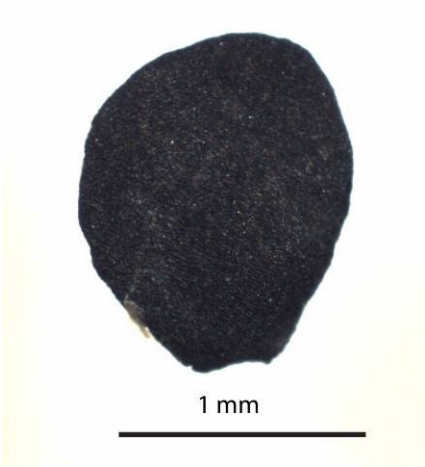


Undet 43

Undet 45

Undet 51

Undet Fabaceae #118



Undet Solanum #199

Appendix E: Table E.1 Weed Flora Present on the Chengdu Plain

Family	Genus	*Species*	Dryland	Wetland	Both	Ref
Amaranthaceae	*Chenopodium*	*acuminatum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*album*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*ambrosioides*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*aristatum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*foetidum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*giganteum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*glaucum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*hybridum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*serotinum*	X			Wang Z. 1990
Amaranthaceae	*Chenopodium*	*urbicum*	X			Wang Z. 1990
Amaranthaceae	*Amaranthus*	*lividus*	X			Song 2012
Amaranthaceae	*Amaranthus*	*roxburghensis*	X			Song 2012
Amaranthaceae	*Amaranthus*	*viridis*	X			Song 2012
Asteraceae	*Acroptilon*		X			Zhou and Zhang 2006
Asteraceae	*Arctium*		X			Zhou and Zhang 2006
Asteraceae	*Artemesia*		X			Song 2012
Asteraceae	*Aster*	*ageratoides*	X			Song 2012
Asteraceae	*Brachyactis*	*ciliata*			X	Song 2012
Asteraceae	*Caardus*	*crispus*	X			Zhou and Zhang 2006
Asteraceae	*Carpesium*	*cernuum*	X			Zhou and Zhang 2006
Asteraceae	*Xanthium*	*sibiricum*	X			Zhou and Zhang 2006
Brassicaceae			X			Zhou and Zhang 2006
Caryophyllaceae	*Arenaria*	*serpyllifolia*	X			Zhou and Zhang 2006

Table E.1(Continued)						
Caryophyllaceae	*Cerastium*	*caespitosum*	X			Zhou and Zhang 2006
Caryophyllaceae	*Cerastium*	*glomeratum*	X			Zhou and Zhang 2006
Caryophyllaceae	*Myosoton*	*acquaticum*	X			Zhou and Zhang 2006
Caryophyllaceae	*Sagina*	*japonica*	X			Zhou and Zhang 2006
Caryophyllaceae	*Stellaria*	*alsine*	X			Zhou and Zhang 2006
Caryophyllaceae	*Stellaria*	*apetala*	X			Zhou and Zhang 2006
Caryophyllaceae	*Stellaria*	*media*	X			Zhou and Zhang 2006
Cyperaceae	*Fimbristylis*	*dichotoma*		X		Wang Z. 1990
Cyperaceae	*Fimbristylis*	*aestivalis*		X		Wang Z. 1990
Cyperaceae	*Fimbristylis*	*miliacea*		X		Wang Z. 1990
Cyperaceae	*Fimbristylis*	*stauntonii*		X		Wang Z. 1990
Cyperaceae	*Fimbristylis*	*alboviridis*		X		Soerjani et al. 1987
Cyperaceae	*Fimbristylis*	*aphylla*		X		Soerjani et al. 1987
Cyperaceae	*Fimbristylis*	*globulosa*		X		Soerjani et al. 1987
Cyperaceae	*Scirpus*	*juncoides*		X		Wang Z. 1990
Cyperaceae	*Scirpus*	*planicumis*		X		Wang Z. 1990
Cyperaceae	*Scirpus*	*tabernaemontani*		X		Wang Z. 1990
Cyperaceae	*Scirpus*	*triqueter*		X		Wang Z. 1990
Cyperaceae	*Scirpus*	*wallachii*	X			Wang Z. 1990
Cyperaceae	*Carex*	*heterostachya*	X			Wang Z. 1990
Cyperaceae	*Carex*	*rigescens*	X			Wang Z. 1990
Cyperaceae	*Cyperus*	*amuricus*	X			Wang Z. 1990
Cyperaceae	*Cyperus*	*difformis*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*duclouxii*		X		Wang Z. 1990

Table E.1(Continued)						
Cyperaceae	*Cyperus*	*fuscus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*glomeratus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*haspen*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*imbricatus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*iria*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*michelianus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*nipponicus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*polisus*		X		Wang Z. 1990
Cyperaceae	*Cyperus*	*rotundus*		X		Wang Z. 1990
Cyperaceae	*Eleocharis*	*tetraqueter*		X		Wang Z. 1990
Cyperaceae	*Eleocharis*	*pellucida*		X		Wang Z. 1990
Cyperaceae	*Eleocharis*	*valleculose*		X		Wang Z. 1990
Cyperaceae	*Eleocharis*	*yokoscensis*		X		
Equisetaceae	*Equisetum*			X		
Fabaceae	*Vicia*	*amoena*	X			Zhou and Zhang 2006
Fabaceae	*Vicia*	*bungei*	X			Zhou and Zhang 2006
Fabaceae	*Vicia*	*cracca*	X			Zhou and Zhang 2006
Fabaceae	*Vicia*	*sativa*	X			Zhou and Zhang 2006
Lamiaceae	*Stachys*		X			Zhou and Zhang 2006
Malvaceae	*Malva*	*rotundifolia*	X			Song 2012
Malvaceae	*Malva*	*verticillata*	X			Song 2012
Only two sp.	*Hackelochloa*	*granularis*	X			Soerjani et al. 1987
Phytolacaeae	*Phytolacca*		X			Zhou and Zhang 2006
Poaceae	*Digitaria*	*adscendens*	X			Wang Z. 1990
Poaceae	*Digitaria*	*sanguinalis*	X			Wang Z. 1990

Table E.1 (Continued)						
Poaceae	*Digitaria*	*ciliaris*			X	Wang Z. 1990
Poaceae	*Digitaria*	*ischaemum*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*crusgalli*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*crusgalli var. caudata*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*crusgalli var. hispidula*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*crusgalli var. mitis*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*crusgalli var. zelayensis*		X		Wang Z. 1990
Poaceae	*Echinocloa*	*colonum*		X		Wang Z. 1990
Poaceae	*Eleusine*	*indica*	X			Wang Z. 1990
Poaceae	*Calamagrostis*	*pseudophragmites*			X	Wang Z. 1990
Poaceae	*Eragrostis*	*amabilis*	X			Wang Z. 1990
Poaceae	*Eragrostis*	*japonica*	X		X	Wang Z. 1990
Poaceae	*Eragrostis*	*cilianensis*	X			Wang Z. 1990
Poaceae	*Eragrostis*	*ferruginea*	X			Wang Z. 1990
Poaceae	*Eragrostis*	*nigra*	X			Wang Z. 1990
Poaceae	*Eragrostis*	*pilosa*	X			Wang Z. 1990
Poaceae	*Eragrostis*	*poaeoides*	X			Wang Z. 1990
Poaceae	*Miscanthus*	*sacchariflorus*	X		X	Wang Z. 1990
Poaceae	*Stipa*	*bungeana*	X			Song 2012
Poaceae	*Aira*		X			
Polygonaceae	*Polygonum*	*amphibium*		X		Wang Z. 1990
Polygonaceae	*Polygonum*	*amphibium var. terrestre*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*aviculare*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*barbatum*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*bungeanum*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*caespitosum*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*convolvulus*		X		Wang Z. 1990
Polygonaceae	*Polygonum*	*hydropiper*		X		Wang Z. 1990
Polygonaceae	*Polygonum*	*japonicum*			X	Wang Z. 1990

Table E.1 (Continued)						
Polygonaceae	*Polygonum*	*lapthafolium*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*maackainum*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*nepalense*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*orientale*				Wang Z. 1990
Polygonaceae	*Polygonum*	*perfoliatum*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*persicaria*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*sagittifolium*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*sibiricum*			X	Wang Z. 1990
Polygonaceae	*Polygonum*	*strigosum*		X		Wang Z. 1990
Polygonaceae	*Polygonum*	*viscosum*		X		Wang Z. 1990
Polygonaceae	*Polygonum*	*plebeium*	X			Wang Z. 1990
Polygonaceae	*Polygonum*	*divaricatum*	X			Wang Z. 1990
Portulacaceae	*Portulaca*	*oleracea*		X		Song 2012
Potamogetonaceae	*Potamogeton*	*distinctus*		X		Wang Z. 1990
Potamogetonaceae	*Potamogeton*	*cristatus*		X		Wang Z. 1990
Potamogetonaceae	*Potamogeton*	*natans*		X		Wang Z. 1990
Potamogetonaceae	*Potamogeton*	*malainus*		X		Wang Z. 1990
Potamogetonaceae	*Potamogeton*	*crispus*		X		Wang Z. 1990
Rubiacee	*Galium*	*sp.*	X			Zhou and Zhang 2006
Solanaceae	*Lycium*	*chinense*	X			Zhou and Zhang 2006
Solanaceae	*Nicandra*	*physaloides*	X			Zhou and Zhang 2006
Solanaceae	*Physalis*	*minima*	X			Zhou and Zhang 2006
Solanaceae	*Physalis*	*angulata*	X			Zhou and Zhang 2006
Solanaceae	*Physalis*	*alkekengi*	X			Song 2012

Table E.1 (Continued)						
Solanaceae	*Hyoscamus*	*niger*	X			Song 2012
Solanaceae	*Solanum*	*alatum*	X			Song 2012
Solanaceae	*Solanum*	*xanthocarpum*	X			Zhou and Zhang 2006
Verbenaceae	*Verbena*	*officinalis*	X			Wang Z. 1990